AUTOGENOUS VEIN GRAFTS

AUTOGENOUS VEIN GRAFTS

AND RELATED ASPECTS OF PERIPHERAL ARTERIAL DISEASE

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John J. Morton, Jr., M.D.

Progress of surgery increasingly depends on principles elaborated in laboratories, especially in physiological laboratories

— Alexis Carrel, 1906

PREFACE

The most significant advances in the field of surgery during the past fifteen years have been those related to abnormalities of the heart and blood vessels. The direct surgical attack on obstructive lesions of the smaller arteries is one of the most interesting phases of this period of rapid development of "Vascular Surgery," and it has stimulated a renewed interest in the problems of vascular obstruction due to atherosclerosis. Until recently, the degenerative process of arteriosclerosis was considered to be one which affected all arteries in a more or less uniform manner although it was known that in some individuals the coronary or cerebral vessels would be the most severely involved. This is, of course, generally true, but it has now become evident that peripheral arteries develop segmental occlusion, and that the process does not involve an individual artery or its branches in a uniform manner. There is a tendency for atherosclerotic obstruction to occur at the bifurcation of arteries where there is perhaps more stress on the wall and in the distal third of the superficial femoral artery where it is restricted by the adductor tendon.

The direct surgical attack on peripheral arterial occlusive disease has stimulated investigation, resulting in a better understanding of many related problems. Methods of diagnosis by arteriography have been improved, the search for better and safer contrast materials has become necessary, and most important of all has been the necessity to evaluate experimentally and clinically the techniques of grafting small arteries. The problem of establishing a suitable graft or prosthesis for large arteries, as the aorta, has offered less of a problem than finding a suitable prosthesis for bypassing a long segment of occlusion in an artery the size of the femoral. The evaluation of clinical results is complicated by the presence of advancing disease in the host artery, and only by a combination of

testing various grafting materials in the experimental animal plus clinical trial can an accurate evaluation result

The author has had a very extensive laboratory experience in using the various materials available for replacing small arteries and the experiments reported are well conceived and accurately controlled The clinical results are presented in an unbiased manner recognizing that the experimental animal does not always accurately reflect the conditions present in the patient and that sufficient time has not as yet elapsed to compare the eventual fate of materials now available It seems most reasonable to assume that the autogenous graft should be most successful in vascular replacement and it should be the yardstick of comparison for inert plastic prosthesis

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INTRODUCTION

WIDESPREAD INTEREST in direct arterial surgery has resulted from new knowledge and experience accumulating in the past decade Extremely rapid progress in any field often results in clinical impressions pushing far ahead of what is warranted by the available experimental and clinical evidence Opportunities to observe the effects of both direct and indirect surgery for arterial disease have increasingly led to the belief that the clinical pattern is often so complicated that properly conceived experiments may clarify clinical situations with considerably more rapidity and accuracy than would occur from impressions derived purely from the study of available patients (although patient study is not to be neglected)

In 1954, study of the problem of small vessel grafts was initially begun in the experimental laboratory and has been continued for approximately five years in an attempt to evaluate this as well as other aspects of direct peripheral vascular surgery

Our initial clinical use of homologous arterial grafts for both aortic and peripheral vascular replacements in humans gradually gave way to the use of synthetic tubes for aortic replacements as these became available and as mounting evidence indicated their usefulness Increasing dissatisfaction with the late results of homologous arterial grafting for peripheral atherosclerosis, coupled with increasing confidence in autogenous vein grafts based on laboratory experience, led to their initial clinical trial for long by pass shunt grafts in May of 1957 * Since that time, the use of homologous arterial transplants has ceased completely (although it is recognized that an occasional one may be required in the future) and either autogenous veins or synthetic tubes have been used entirely for arterial replacement

This monograph centered about the use of autogenous vein

*Earlier short end to-end or by pass vein grafts placed for trauma have been specifically excluded from this experience since they were done without any overall general pattern and by varied technics and have been poorly followed

grafts has been prepared following a suggestion that collection and criticism of available information would be of value to those interested in continuing efforts to determine the proper indications for and materials useful in direct arterial surgery While it appears to the author that the available experimental and clinical information indicates that autogenous venous shunt grafts are preferable to other currently available materials for by passing atherosclerotic lesions of the femoro-popliteal system, it is to be emphasized that modern clinical experience with these is relatively small and that long term accurate follow ups are pitifully meager It may indeed be said that accurate long term follow ups of all types of direct arterial surgery are scanty and that with a few shining exceptions, most patients have been essentially lost to follow up once the immediate post-operative period ended A pressing need for proper long term studies of all forms of direct peripheral vascular surgery is apparent.

Particular appreciation is expressed to Dr W J Merle Scott, himself a pioneer in the field of surgery of the vascular and autonomic nervous systems for his continued enthusiasm support and often original thoughts in connection with these problems Appreciation is similarly expressed to Dr Herman E Pearse whose early contributions to arteriography and peripheral embolectomy have helped lay the groundwork for modern advances To Dr Earle B Mahoney is expressed gratitude for his constantly inspiring teaching emphasis upon the experimental approach to surgical progress and the pursuit of the frontiers of clinical surgery

Laboratory and clinical colleagues including Dr James A De Weese Dr Theodore I Jones, Dr Raymond J Hinshaw, Dr F N Niguidula and Mr George E Mavor, F R C S have been responsible for much stimulation as well as actual work involved in various studies

Dr Stanley Rogoff has been most patient and cooperative in relation to both experimental and clinical angiography Appreciation is expressed to Dr H William Scott Professor and Chairman of the Department of Surgery, Vanderbilt University for his recent interest and cooperation in continued study of these problems

Mr John Gaughan, Mr Grant Lashbrook and Mr Richard

Myers have been most helpful in preparing illustrations. Particular appreciation is expressed to Mrs. Marjorie Gabel for her unfailing devotion to the laboratory animals and experiments from 1953 to 1958 at the University of Rochester. Mrs. Margaret Nielsen has patiently and faithfully prepared the manuscript. Finally, it is a pleasure to thank Mr. Charles C. Thomas and Mr. Payne E. L. Thomas for their courteous and cooperative aid with this volume.

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Chapter I

HISTORICAL ASPECTS

THE HISTORY of peripheral vascular disease dates to antiquity While the brief average life span in early times no doubt precluded a high general instance of arteriosclerosis such has been found in Egyptian mummies and the Greeks recognized senile gangrene although its cause was unknown The violence of the times certainly must have made the results of acute traumatic vascular insufficiency quite evident even though the physiologic details were not understood

Although the ancients used the ligature to control hemorrhage and devised methods of ligation for peripheral aneurysm there was general loss of the main body of this knowledge during the Dark Ages Ambrose Pare in 1552 revived control of bleeding by ligature (although this mass ligation of all tissues in the vicinity of the bleeding vessel was considerably more gross than the modern technic implied by the term) Thereafter there was constant competition between ligature cautery compression and other methods of hemorrhage control until the end of the 18th century when ligation became generally recognized as the best hemostatic method During this period of intellectual awakening circulation of the blood had been demonstrated by William Harvey in 1628 and many pathologic conditions had been clearly described [1] including arteriosclerosis by Leonardo da Vinci and by the Italian anatomist Gabriel Fallopius and descriptions of atheromata atheromatous ulcers and thrombosis at the site of atherosclerotic lesions

Information on aneurysms accumulated and there was differentiation of syphilis and arteriosclerosis as a cause of these Arteriovenous fistulae and dissecting aneurysms were recognized by William Hunter and Morgagni respectively in the 18th century and the pathologic findings of thromboangiitis obliterans were described in 1879 by the German surgeon von Winiwarter (followed in 1908 by Leo Buerger's[2] report and description of 30 clinical cases)

The first successful vascular repair is credited to Hallowell in 1759 when he sutured a wounded brachial artery by passing a pin through the wound edges and drawing a thread about the ends of the pin In 1879 the Russian surgeon Eck first united two blood vessels when he created a portacaval shunt which thereafter came to bear his name[9] Sir Astley Cooper– performed aortic ligation for aneurysm in the 19th century and Rudolph Matas performed the first endoaneurysmorrhaphy toward the end of that period [9]

A new phase of laboratory investigation began in the late 19th century when various investigators described technics of suturing the blood vessels of animals and in 1897 John B Murphy of Chicago successfully repaired a severed femoral artery by an in vagination method based upon his own animal experiments The first vein graft was placed into the carotid artery by Gluck [1]

Just after the turn of the 20th century Alexis Carrel system atically investigated laboratory methods of vascular suture in dogs and in 1902 first attempted end to end suture of the femoral vein to the femoral artery in a large dog while working in France The animal died of infection two days later His vascular investigations continued after moving to the University of Chicago and he and C C Guthrie not only developed methods of lateral and end to end vascular suture but also transplanted free segments of veins and arteries and investigated the transplantation of extremities and organs [5] Carrel s advice on vascular technic is still valid the vessels were handled very gently and the endothelium was pro tected from drying by isotonic sodium chloride solution or by sterilized vaseline No dangerous metallic forceps were used Great care was exercised to obtain accurate and smooth approximation of the endothelium of the vessels stenosis or occlusion only occurs as a result of faulty technic [6-8] In 1912 Carrel was awarded the Nobel Prize in medicine in recognition of his works on vascu lar suture and the transplantation of blood vessels and organs [31]

Others became interested and in 1907 Watts[14] summarized the history of vascular surgery to that date and reported experi ments in which he had transplanted two veins one remaining patent for 26 days An occasional successful clinical vein graft was

done[18, 23] and in 1913 Pringle[30] reported two autogenous vein grafts for aneurysms of the popliteal and brachial arteries respectively Guthrie[20] also continued the study of venous as well as arterial transplants and just prior to World War I discussed the possibility of arterializing the venous system of the leg in peripheral vascular insufficiency as had been suggested earlier

Little use was made of the vascular technics developed by Carrel during World War I Sir Henry Makins[26] monograph on surgical experience during World War I indicated that in the British service little direct vascular repair was possible although there were some attempts to use Tuffier s tubes (of paraffin lined silver) to allow temporary blood flow across an arterial defect while vascular collateral developed Bernheim[2] has pointed out that infection and fear of its effects upon vascular suture lines prohibited reparative surgery in World War I and confined surgical efforts to salvage of life by debridement and ligation even at the risk of loss of limb

During the interbellum period other progress such as the development of the clinical use of heparin[8] and development of lumbar sympathectomy occurred The outbreak of World War II stimulated immediate interest in traumatic vascular problems The development of the non suture vein graft technic of Blakemore Lord and Stefko[3] in 1942 was directed toward wartime use but was not practically successful This method utilized vitallium tubes through which a vein graft was passed and to the ends of which the artery was ligated and was similar to the earlier Payr tubes[20] and to Crile s transfusion cannula[11] developed in 1909 After the war DeBakey and Simeone[13] found that this technic had been used at least 40 times without decreasing the amputation rate from that occurring with simple ligation Smith s[3] analysis in 1947 corroborated this

The development of intrathoracic technics for use upon the heart and great vessels by Crafoord[10] Gross[18] Blalock[4] and others led to renewed interest in central vascular surgery and encounters with anomalous situations led to the need for suitable grafts to bridge defects Various methods of preservation of homologous arterial grafts were developed from 1949 on and these also

began to be used to replace peripheral segments occluded by atherosclerosis. Kunlin[22] in 1951 reported his experience with 17 long vein grafts for atherosclerotic femoral occlusion dating back to 1948. It was soon recognized that simple by-pass shunting about a blocked area was as successful functionally and less dangerous than resection of the diseased area with replacement grafting.

Since the 1952 report of Voorhees, Jaretzki and Blakemore[34] on the use of a synthetic fabric tube (Vinyon N) to act as a blood vessel, a large number of porous synthetic tubes have been devised and used with various degrees of success. The development of the crimping technic by Edwards and Tapp[16] led to proper flexibility when applied to several synthetic tubes. Reports of experimental and clinical experience by Linton,[24] Edwards,[15] DeBakey and associates,[12] Julian,[21] Deterling,[14] Szilagyi[33] and others led to widespread use of a variety of tissue and synthetic tubes to by-pass occluded peripheral arteries, which either temporarily or for long periods improved function and salvaged extremities. Homologous arterial grafts were used in increasing numbers and efficient arterial banks were developed until it was realized that there was an increasingly high incidence of late graft degeneration and complications as time progressed. Increasing availability of synthetic tubes[12, 14, 16, 21] coincided with the recognition of the disadvantages of arterial homografts and resulted in widespread use of synthetic tubes for large as well as small caliber grafts.

While the autogenous venous graft has been occasionally used experimentally as well as clinically for a long time, its utilization never became as widespread as that of either homologous arteries or synthetic tubes. Whether this was due to difficulty in use of autogenous veins or to misunderstanding of its virtues and drawbacks is not easy to say. On the following pages information pertinent to this question is discussed.

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Chapter II

EXPERIMENTAL VEIN GRAFTS

Any of a great variety of materials can be successfully transplanted into a large canine vessel such as the thoracic or abdominal aorta to serve as a splint while a neo intima covers the inside of the material and a fibrotic sheath encloses the external surface A Committee of the Society for Vascular Surgery reported in January 1957 that 27 different surgeons had used 17 types of 8 basic materials to replace 709 dog aortas with 87% patency[8] Harrison reported that only 1 of his 84 thoracic aortic tubes in dogs had thrombosed[1] An independent survey by the author in 1958 similarly showed 83% patency in 863 reported canine aortic replacements[10] and laboratory experience (summarized in Table I) showed that 70% of 37 aortic prosthetic grafts of several types remained patent

Experience in shunting small peripheral canine vessels has on the other hand been poor The Committee of the Society for Vascular Surgery reported that only 46% of 96 synthetic grafts of less than 8 mm diameter had remained open[8] Our summary of the published literature in 1958 showed only one patency of 39 experimental synthetic tubes clearly reported as less than 8 mm diameter[10] Table I indicates that only 29% of the various 68 peripheral synthetic shunts in dogs remained patent

The poorer patency results of synthetic tubes replacing canine peripheral arteries rather than aorta indicates the more severe test furnished by the canine peripheral arterial shunt graft experiment Although any of several materials will perform satisfactorily as aortic replacements peripheral canine grafting is a considerably more critical test of any material Because of the inherent difficulty of performing such relatively small anastomoses and of transplanting such relatively small grafting materials this severe test of a grafting material has in general been overlooked or deemed not feasible However experience in this laboratory indicates that aorto iliac ilio femoral and femoro femoral shunt grafting in large

or moderate size dogs can be accomplished satisfactorily with homologous arteries and autogenous veins. Since long term follow up of these animals excludes blockage of the graft by the progression of (atherosclerotic) disease, this peripheral canine graft preparation appears to be good (and severe) test of the inherent qualities of any grafting material without the confusing element of a progressive disease process.

Experimental Methods

Operations were performed under intravenous Nembutal anesthesia using technic as similar as possible in that employed in the clinical operating room. Sutures were 4-0 and 5-0 silk* and every effort was made to manage tissue with sharp, delicate and aseptic technic. No antibiotics were used unless the thoracic cavity had been opened, in which case daily procaine penicillin injections were given.

Anastomotic technic using continuous 5-0 silk consisted of an everting mattress suture at two opposite points followed by an over-and-over continuation of each suture until it could be tied to the other. End-to-side anastomoses were performed so that the diameter of the stoma was approximately three times that of the lumen of the host vessel. Heparinized saline (50 mg. per 200 cc.) was used to wash out the vessels immediately after they were opened but no general heparinization was utilized except temporarily during by pass pump shunting of the thoracic aorta in certain animals. Figure 1 illustrates the completed end-to-side anastomosis of an autogenous saphenous vein to the femoral artery of a dog.

Arteriograms were made at intervals by injecting 14 cc. of 35% sodium acetrizoate (Urokon sodium)* either percutaneously into the abdominal aorta or by a catheter threaded retrograde into the aorta via the contralateral femoral artery.

Autopsy examination was done either at the time when arteriograms showed graft occlusion or at a time selected for sacrifice.

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*Materials were kindly furnished by the following commercial concerns without cost for which appreciation is expressed. Arterial silk and Ethi graft merselene from Ethicon Inc., Urokon from Mallinckrodt Chemical Works. Fl[illegible]n dacron from Bentley Harris Mfg. Co., Crimped nylon from The Chemstrand Co., Schlegel nylon from the Schlegel Mfg. Co. Teflon from John P. S[illegible]lebotham Inc.

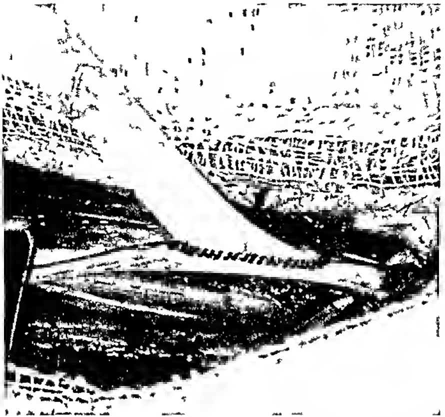

Fig 1 Completed anastomosis between canine saphenous vein and femoral artery to illustrate suturing and relation of anastomosis size to vessel size Surrounding material consists of ordinary surgical gauze sponges (Courtesy of the *British Journal of Surgery 46* 198 1959—Dale and Mavor)

if the graft remained patent Microscopic sections were made of selected specimens

Autogenous veins were obtained by carefully dissecting the saphenous vein of the animal and ligating its tributaries with 4 0 silk The vein was washed out with heparinized saline immediately after its removal and was reversed prior to placement in order that the valves would point in the proper direction Great care was taken to prevent damage of the thin venous wall by avoiding steel instrument placement on any part of the graft which was to be used

Homologous arteries were obtained aseptically from dogs sacrificed in the laboratory for other purposes cultured and

stored in penicillin streptomycin solution for 21 hours at 4° centigrade and then stored in a deep freeze as –20° centigrade They were reconstituted by returning the graft to room temperature and adding saline solution Arterial branches were sutured-ligated with 5 0 silk

Synthetic prostheses were boiled for an hour in a detergent and washed in tap water prior to autoclaving Some of the first prostheses were not preclotted, but later ones had intraluminal injection of fresh autogenous blood in order to control bleeding through the porous material Flullon dacron* protheses were cut to size with scissors and cut along one side of the tube so that a cuff could be turned back for suturing Crimped nylon* prostheses were cut with scissors and the obliqued ends sealed lightly with the actual cautery Teflon* prostheses were boiled in concentrated sulfuric acid for a week to remove brownish discoloration due to impurities and cut along one side so that a flange could be used for suturing Ethigraft merselene* prostheses were cut to size by passing an actual cautery quickly across the tube and then gently prying the ends apart Sheet orlon prostheses were sewn in tubes from commercial squares of orlon cloth Schlegel nylon** tubes were trimmed into an oblique end shape and lightly sealed by cautery prior to anastomosis.

Homologous Arterial Grafts

Many corroborating studies of homologous arterial replacement of dogs' aortas have been reported and indicate that such grafts may be preserved by any number of ways and will function for a long period satisfactorily, although the incidence of degeneration increases with time. A small number of aortic end-to-end homografts were transplanted to learn initially the technic of vascular anastomoses and to verify the reports of others sited above. There was no particular difficulty with these, and long-term study of a few of these shows results which are similar to those noted below for peripheral homografts.

*Materials were kindly furnished by the following commercial concerns without cost for which appreciation is expressed Arterial silk and Ethi graft merselene from Ethicon, Inc., Urokon from Mallinckrodt Chemical Works, Flullon dacron from Bentley, Harris Mfg Co Crimped nylon from The Chemstrand Co; Schlegel nylon from the Schlegel Mfg Co., Teflon from John B. Sidebotham, Inc.

**The majority of these were placed by Dr J R Hinshaw

George Mayor in 1956 initially reported laboratory experience here with by passing shunt arterial homografts and showed that the results in short shunt homografts were excellent and slightly poorer in long shunt homografts (placed beneath the inguinal ligament to connect the iliac and femoral arteries) [10] Some increase in the series and further analysis of this occurred later and is summarized in Figure 2 which indicates that of the 43 homografts studied, 14 became thrombosed and 29 remained patent [9] The 4 thrombosing after arteriography may have done so because of the dye injection or may have been about to thrombose shortly in any event The 67% gross patency represents a minimum figure since it includes

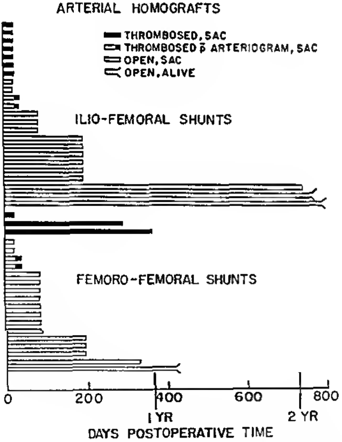

Fig 2 Summary of 43 experimental homologous arterial grafts in dogs (Courtesy of *British Journal of Surgery, 46* 193 1959—Dale and Mayor)

those grafts thrombosing after arteriograms and also since it includes the early grafts during which time technical experience was being accumulated. Later homologous arterial shunt grafts have been placed (which are not included in this series) without particular difficulty and it is believed that a considerably higher patency percentage could be achieved were it thought worthwhile to repeat the series. Experience with these homologous arterial grafts definitely showed that canine peripheral vessels could be shunt grafted with a high degree of success as had been learned earlier by Miller, Callow, Welch and MacMahon.[20]

Arteriographic follow up of the homologous arterial transfers did not show any dilatation or aneurysm formation and in fact showed some slight decrease in length and in diameter which no doubt represented fibrosis occurring with time.

Only 4 of the peripheral arterial homografts were followed for long periods of time because of the expense and difficulty of long term dog maintenance. These 4 were for 416, 723, 765 and 770 days respectively (Table IV). They showed a 1 to 2 mm decrease in the vessel diameter grossly. Microscopic examination showed fibrosis to the point where there essentially was replacement of the original tissue. There were clumps of disconnected broken elastic fibers, and only occasional remaining smooth muscle cells.

Synthetic Tube Grafts

The experiences of others as well as personal experimental results have been briefly discussed above as denoting difficulty in placing synthetic tubes in dogs' peripheral arteries which would remain patent for a long period. Of a total of 118 synthetic tubes (Fluflon dacron, crimped nylon, woven Teflon, Edu-graft dacron and sewn sheet orlon) placed in various arterial positions in dogs, 105 were properly studied and published in detail in 1959.[19] The IIIa and IIIb portions of Table I summarize the patency data and contrast the relatively good results of prosthetic tubes over 8 mm internal diameter (70% patency in 37 dogs) with the poor results when the synthetic tube was less than 6 mm diameter and placed peripherally (29% patency in 68 dogs). Comparison of the large

TABLE I

SUMMARY OF 190 CANINE PERIPHERAL SHUNT GRAFTS

Occlusion early indicates failure of first arteriogram to show patency while occlusion late denotes thrombosis after early patency shown by arteriogram Synthetic tubes included crimped and non crimped nylon Fluflon dacron and flanged dacron and orlon tubes

No	Site	Graft Results			
		Occlusion		Patent	
		Early	Late	No	%
	I Autogenous Vein"				
5	ilio femoral	0	0	5	100%
37	femoro-femoral	15	1	21	57%
42	Total Veins	15	1 (2%)	26	62%
	II Homologous Artery"				
23	ilio femoral	7	2	14	61%
20	femoro femoral	3	2	15	75%
43	Total Arteries	10	4 (9%)	29	67%
	IIIa Small Synthetic Tubes"				
23	aorto iliac	8	2	13	57%
9	ilio femoral	7	2	0	0%
36	femoro femoral	23	6	7	19%
68	Total small prostheses	38	10 (15%)	20	29%
	IIIb Large Synthetic Tubes'				
31	aortic end end	8	3	20	65%
6	aortic shunt	0	0	6	100%
37	Total large prostheses	8	3 (8%)	26	70%

synthetic tubes with the autogenous vein and homologous artery patency figures (62 and 67% respectively) shows similarity *

This canine experience indicates that while it may be possible to place a large bore, non pliable piece of material into a large vessel such as the abdominal aorta that these undesirable characteristics are immediately emphasized when a similar tube of smaller diameter is placed into the peripheral system An aortic replacement may function satisfactorily even though synthetic fibers protrude across the suture line but this will usually result in thrombosis in a small tube

There appear to be two reasons for the poor patency results with synthetic tubes Despite the utmost care at the time of operation, there was often anastomotic constriction and postmortem examin

*All figures include every dog studied and are therefore uncorrected for any factor

ation in this situation would show a thrombus limited to the anastomotic area with a completely empty graft otherwise Certain other grafts were completely thrombosed however and it was thought that these did not necessarily represent failure at the site of anastomosis but more likely represented deposition of a thick neointima with thrombosis due to general narrowing of the lumen The thickness of the new lining of a synthetic tube is considerably greater than that of a transplanted homologous artery or of an autogenous vein graft as is shown in Figure 7 so that diameter for diameter a considerably smaller vein graft will eventually have a larger lumen than will either artery or synthetic tube of the same initial lumen diameter

An attempt was made to study differences between several synthetic tubes in order to learn which of the available materials would be preferable for prosthetic replacement in humans There was not a great deal of difference and the surgeon should therefore choose the one which can be most easily handled at operation in terms of suturing proper porosity and non fraying of edges *

Autogenous Vein Grafts

Because a general impression has become prevalent that vein grafts (particularly into large arteries such as aorta) frequently form aneurysms the experimental as well as clinical literature was surveyed

Sako[24] in 1951 reported initial dilatation of autogenous vein grafts replacing dogs thoracic aorta but serial aortograms showed no further enlargement after five or six weeks

Johnson Kirby and associates[13] found graft dilatation but no aneurysm formation in 12 dogs followed up to 14 months after vena caval transplantation into the abdominal aorta However they later reported in *1951*[14] and *1953*[16] that 5 pig thoracic transplants were greatly dilated and 2 of these definitely aneurysmal

Schmitz Kanar Sauvage Storer and Harkins[3] in 1953 re-

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*Since these particular experiments were performed newer materials such as crimped teflon and micro-crimped dacron have become available and are specifically excluded from the above comments From inspection and initial clinical use they appear to be superior to all the above materials

ported that autogenous veins tended to dilate when placed into the abdominal aorta of 42 young pigs and 36 mature dogs Despite various measures (such as Latex, plication [37] and muscular pedicle [25]) to prevent venous graft dilatation, Nyhus and Harkins [26] in 1957 again reported dilatation to be common when vein replaced aorta experimentally but had no difficulty when using saphenous vein to replace femoral artery clinically and preferred this as the graft choice The same group [13] later discussed the five year follow up of 4 venous aortic grafts with excellent function in all despite dilatation

Nabatoff, Touroff and Gross [illegible] reported that 6 dogs with venous aortic grafts in place 1 to 4 years showed dilatation and aneurysm formation but none ruptured

These and other pertinent series are summarized in Table II Six series of caval grafts into *pig* aortas showed aneurysms in certain instances Some degree of dilatation was common but in only one of the series of caval transplants in *dog* aortas did actual aneurysm occur,[29] suggesting the possibility of a species difference in susceptibility of venous grafts to aneurysm formation In the four series of autogenous vein grafts placed into the femoral artery there was reported non progressive dilatation but no aneurysm formation Sauvage and Wesolowski [29] in 1955 reported that 7 of 8 autogenous femoral veins remained patent as femoral arterial grafts 6 to 12 months Four showed non progressive dilatation, but microscopic study showed anatomically intact structures with preservation of venous valves The series of 42 experimental peripheral grafts of Jones and the author likewise showed mild but non progressive dilatation without aneurysm formation [17]

The above experimental evidence along with clinical reports (Chapter III) indicating only two reported small aneurysms in peripheral vein grafts should quell fears of this complication

The supposed difference in aneurysm formation when veins are placed into the aorta vs femoral artery has in the past been ascribed to a lack of muscle and/or fascial support of a graft lying within the chest or abdomen whereas such is present when vein grafts are placed in extremities More careful consideration of this proposition indicates a fallacy because when a vein graft is placed into the

Zech Nylius, Kanar, Schmitz, Sauvage, Moore, Fletcher, Merendino, Harkins (38)	1954	inf cava (dicetyl po. added)	thor aorta (pigs)	6 E E	3 dilatation, 3 good	8 269 days
Nylius, Kanar Moore Schmitz Sauvage, Zech, Harkins (21)	1955	inf cava	thor aorta (pigs)	10 E E	6 dilatation 3 good 1 thrombosis	1 253 days
Nylius Moore, Zech, Kanar, Griffith, Eade Harkins (25)	1956	inf cava (supported)	thor aorta (pigs)	10 E E	9 dilatation, 1 good	68 348 days
Zech, Nylius, Eade, Harkins (37)	1956	inf cava (Latex or plication)	thor aorta (pigs)	11 E E	all dilated or formed aneurysms	200 250 days
Jesseph, Jones, Sauvage, Kanar, Nylius Harkins (13)	1958	2 jugular 1 inf cava 1 caval homograft	late follow up of above	4 E E	all showed non progressive dilatation	5 years
Nabatoff, Touroff, Gross (22)	1955	inf cava	abd aorta	4 E E	all patent with aneurysms	1 4 years
Sauvage, Wesolowski (29)	1955	femoral	femoral artery	8 E E	7 patent, 4 non progressive dilatation	to 1 year
Southgate, Tomon Mahoney (34)	1955	inf cava	thor aorta	3 E E (plastic wrap)	2 no dilatation 1 moderate dilatation	88 429 days
Jones, Dale (17)	1958	saphenous	femoral artery	42 shunts	some dilatation, no aneurysms	to 790 days

popliteal space or in the femoral region it is certainly not completely enclosed by fascia or muscle Furthermore in the experimental series conducted by Nylins and associates it was found that pedicled muscle grafts placed about autogenous vena cava (of pigs) transplanted into the thoracic aorta failed to prevent dilatation and aneurysm formation in the pigs It has been proposed by us[1] that a more likely explanation for the behavior of the vein graft appears to lie in Laplace s law which states that

$$T = P \times R$$

where T is the tension within the wall of a cylinder P is the pressure within and R is the radius of the cylinder This law has been discussed and analyzed by Burton[4] It seems likely that since there is little variation in the blood pressure (P) between the aorta and the femoral system that the tension (T) in the wall of the vein is primarily the result of the radius (R) and that while a vein with a large diameter may develop too much tension (T) because of its great radius a smaller one will not With the realization of the species difference in incidence of development of aneurysms in large vein grafts it seems likely that the inherent strength characteristics of the vein wall dependent upon its elastic and collagenous fibers may be overcome more easily by the wall tension (T) in pigs than in dogs Peripherally the vein wall is apparently strong enough to resist aneurysm formation Figure 3 shows autopsy examination of a canine vein graft at 567 days

A series of 42 peripheral autogenous vein grafts reported by Jones and the author[3] in 1958 has been expanded by further experience both in the laboratory and clinically without any change in the conclusions which were drawn from that series An overall patency of 62% was reported as shown in Table I and Figure 4 indicating the times of study The 42 grafts include early grafts during which more difficult technic of a vein graft was being learned and it should be emphasized that later experience has been better than this 62% figure indicates (86% patency if results are taken only after each operator s first success) Table III shows the consecutive vein grafts placed by two operators to indicate the increasing rate of patency as experience was gained The penalty of a technically poor procedure is attested by the occurrence of three in

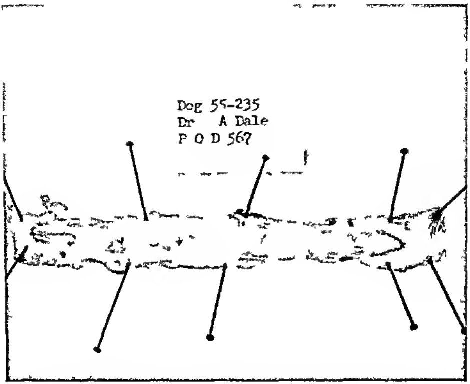


Fig 3 Canine autogenous venous transplant removed at secondary operation 567 days after implantation

bosis in eight of nine grafts judged poor technically at conclusion of operation

These experiments led to the belief that with experience one can shunt graft the femoral arteries of dogs with autogenous veins with predictable success Later operations in the laboratory bear this out

Of interest also are the late patency results There was only a single instance of late occlusion by arteriography after a previous patient graft by x ray and that followed secondary surgical exploration to determine the gross characteristics of the graft and to make intraluminal pressure measurements

In Figure 4 are shown certain autogenous vein grafts placed from iliac artery to femoral artery beneath Poupart s ligament None of the 5 thrombosed Despite thought by some that a semi

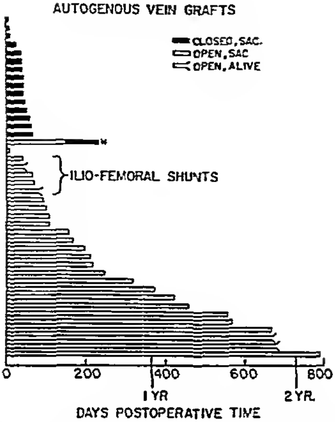


Fig 4 Summary of 42 peripheral autogenous venous shunt grafts in dogs.[3] (Courtesy of the *British Journal of Surgery* *46* 198 1959—Dale and Mavor)

rigid wall is necessary to hold open the graft lumen, it must be recognized that it is the blood pressure which does this An empty artery is almost as pliable and soft as a vein graft, both are kept open by proper blood pressure within

Arteriograms

Each animal was studied by serial arteriograms until this indicated graft occlusion (and autopsy of the animal) or until an elective time for autopsy was chosen The initial arteriogram was performed approximately 30 days after operation and further checks made at approximately 6 month intervals In none of the experimental autogenous vein grafts in Figure 4 was there aneurysm

by x ray or at post mortem examination nor has such dilatation become apparent in any graft done later and not included in that figure Commonly, there was some irregular tortuosity on the arteriogram which distinguishes an autogenous venous from a homologous arterial graft as shown in Figure 5 The arteriographic studies clearly indicated that most veins develop a small degree of dilatation over the original size but that this remained stable over the period studied Table IV summarizes serial arteriograms on 10 autogenous vein grafts and 4 homologous artery grafts in place in the femoral artery of dogs for periods over one year In general, the autogenous vein grafts showed early slight dilatation which remained stable but had no decrease in overall length The homologous arteriograft on the other hand did not increase in diameter but showed a gradual decrease in both length and diameter These contrasting findings are probably due to continued viability of an autogenous vein while a homologous artery acts as a splint and is gradually enveloped by pseudo intima and exterior fibrous reaction with contraction due to maturation of fibroblastic tissue

TABLE III

CONSECUTIVE CANINE VENOUS SHUNT GRAFTS TO SHOW EFFECT OF INCREASING EXPERIENCE (OF TWO OPERATORS) UPON SUCCESS

	Operator #1	Operator #2
	Closed	Closed
	Died 2nd day	Closed
	Closed	Closed
	Closed	Closed
	Closed	Closed
	Open	Died 3rd day
	Closed	Closed
	Open	Closed
	Closed	Open
	Open	Open
	Open	Open
	Open	Open
	Open	Open
	Open	Open
	Open	Open
	Open	Open
	Closed	Open
		Open
		Open
		Open
Patent/Total	9/17	12/20

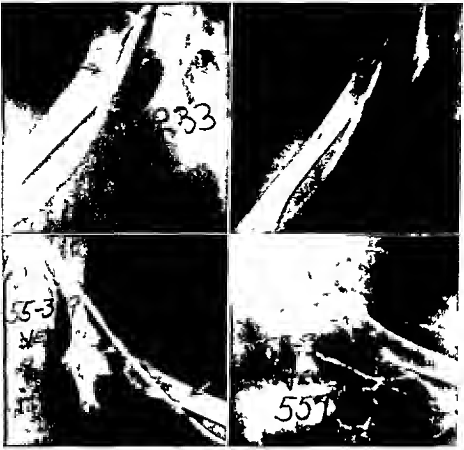


Fig 5 Repetitive arteriographic studies of autogenous venous shunt grafts in dogs to show mild degree of nonprogressive dilatation *Above* are arteriograms at 48 days and 315 days in the same animal *Below* are arteriograms at 9 months and again at 557 days in the same animal

Microscopic Study

Forty five slides from 15 autogenous venous grafts were studied to determine the pattern 5 to 790 days after operation Invariably there was endothelium which appeared to be viable (Figures 6 and 7) with fibrous thickening of all layers of the specimens but without characteristics by which the early specimens could be distinguished from the older ones There was little change in either the endothelium smooth muscle or elastic tissue in the wall of the vein although there was some fibrous infiltration into the media and

TABLE IV

COMPARISON OF SERIAL ARTERIOGRAMS ON 10 AUTOGENOUS VEIN GRAFTS AND 4 HOMOLOGOUS ARTERY GRAFTS IN DOGS FEMORAL ARTERIES OVER ONE YEAR

Arteriographic Follow up Days	*Change in Vessel Diameter*		*Tension*	*Comment*
			Autogenous Venous Grafts	
790	Generalized 1 mm	↑	Tight	Early slight but stable dilatation No decrease in length
680	No Change		Tight	
566	Generalized 2 mm	↑	Loose from start	
664	No Change		Mod loose	
545	No Change		Tight	
404	No Change		Tight	
556	Generalized 1 mm	↑	Slightly loose	
485	No Change		Mod loose	
420	Generalized 1 mm	↑	Loose	
386	Generalized 1 mm	↑	Loose	
			Homologous Arterial Grafts	
770	Generalized 0.1 mm	↓	Tight	Gradual decrease in length and diameter
723	Generalized 1 mm	↓	Tight	
765	Central 0.1 mm	↓	Tight	
416	Central 1.2 mm	↓	Tight	

adventitia (Figure 7). The microscopic studies in general agree with the findings of Schloss and Shumacher[31] who in 1950 summarized reported histological observations on venous autografts ranging in age from 8 to 801 days as showing viability with fibrous reinforcement of the wall of the graft.

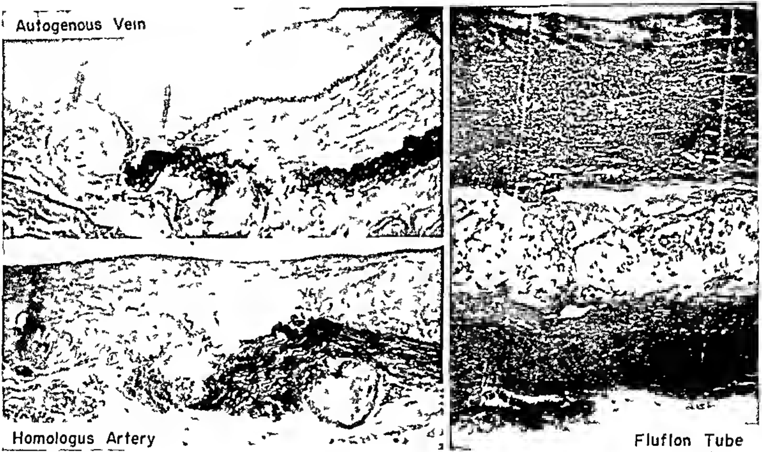
Murray[21] reported in 1952 that a venous autograft recovered from the carotid artery of a dog after 9 years showed some arteriosclerotic change at one area and that on section there was a small amount of bone in the region.

Figure 7 contrasts the microscopic appearance of an autogenous vein with a homologous arterial graft and a synthetic tube of Fluflon dacron. The considerable difference between the viable

autogenous vein graft and the homologous arterial graft may be seen. The arterial graft appears as a fibrous tube with clumps of unconnected frayed elastic tissue and only rare smooth muscle cells. The synthetic tube has been infiltrated to some extent by fibrous tissue and is covered externally by a thick area of fibrosis. The inner pseudo-intima or neo-intima is a particularly thick layer of fibrous tissue with flattened cells on the surface next to the blood stream. The pseudo-intima in many of these specimens is actually

Fig. 6. Photomicrograph of autogenous venous shunt graft removed from a dog 568 days after implantation showing thickening but preservation of the layers. A delicate valve projects upward. (Courtesy A. M. A. Archives of Surgery 76:294, 1958—Jones and Dale.)

Fig. 7. Photomicrographs comparing autogenous venous shunt graft, homologous arterial shunt graft and Fluflon dacron synthetic shunt graft. The autogenous vein has well preserved walls although there is thickening. The homologous artery shows fibrosis with loss of media and fragmentation of elastic fibers. The synthetic dacron tube is seen as the relatively blank area in the center, above which is the neo-intima almost twice as thick as the wall of the plastic tube.


Autogenous Vein
Homologus Artery
Fluflon Tube

thicker than the wall of the synthetic tube itself and explains the luminal diminution found in synthetic grafts of small diameter

Pulse and Flow Transmission Through Grafts

Phelan and Herrick[27] have pointed out that a reversed vein graft best complies with Gibson's[11] concept of minimal loss of pressure and optimal flow when fluid flows through a long tube whose walls are slightly divergent They observed least turbulence in glass models of this type and Schmitz Kanar Sauvage Storer and Harkins[2] observed least alteration in the stream of blood flow in autogenous venous grafts with distal positive disproportion (proximal vein of same size as artery but distal vein larger)

The transmission of the pulse pressure through grafts of various types in the femoral shunt position as well as in the aorta does not appear to be effected by the type graft A study of 9 autogenous veins placed as femoral shunts of 2 homologous arteries similarly placed and of 20 synthetic tubes of 4 different materials placed in varied positions is shown in Table V From this will be seen that both immediately and postoperatively as well as in the late postoperative period there was no reproducible pattern of transmission of pulse pressure Figure 8 shows the pulse proximal and distal to an autogenous venous shunt graft which outwardly appeared to have excellent vascular anastomosis The diminished distal pulse pressure caused investigation of the anastomosis and removal of a clot from one This was immediately followed by increased amplitude of the distal pulse (not shown in the figure) and this finding suggested that any distal diminution of large degree is usually due to either a constrictive anastomosis or thrombus within the lumen Despite suggestions to the contrary[30] synthetic grafts also carry the pulse pressure without any significant diminution These early and late postoperative studies of veins arteries and synthetic tubes indicate that there is little to choose between them so far as pulse transmission is concerned[23]

These laboratory experiences added to other reports indicate why an autogenous vein may be preferable to a synthetic tube of similar diameter and led to their initial use clinically

TABLE V

Transmission of Pulse Pressure by Veins Arteries Four Different Synthetics and a Glass Tube in 32 Dogs

				Pulse Pressure		
	P O	Graft		Proximal	Distal	Change
Dog	*Day*	*Position*	*Length cm*	*mm*	*mm*	*mm*
		Autogenous Vein				
346	0	Femoral shunt		12	1.5	−10.5
375	0	Femoral shunt		21	13	− 8
387	0	Femoral shunt		45	65	+20
118	0	Femoral shunt		56	65	+ 9
290	0	Femoral shunt		21	10	−11
233	0	Femoral shunt		24	28	+ 4
18	0	Femoral shunt		35.5	27	− 8.5
290	211	Femoral shunt		19	9	−10
119	790	Femoral shunt		18	18	0
		Homologous Artery				
440	330	Femoral shunt		43	37	− 6
239	327	Femoral shunt		17.5	13.5	− 4
		Woven Nylon Tubing				
483	298	Aortic e e	6	15	20	+ 5
331	390	Aortic e e	5.5	15	20	+ 5
342	370	Aortic e e	4.5	15	15	0
71	486	Femoral shunt	5	50	50	0
		Crimped Nylon				
307	732	Aorto iliac shunt		30	30	0
238	532	Aorto iliac shunt	5	15	20	+ 5
454	407	Aorto iliac shunt	9	50	55	+ 5
373	735	Aorto iliac shunt	4	25	25	0
410	0	Femoral shunt		30	30	0
188	302	Thor abd shunt	23	30	27	− 3
243	336	Thor abd shunt	24	28	32	+ 4
260	501	Abd aortic e e	6	25	50	+25
24	534	Abd aortic e e	5	17	17	0
304	273	Abd aortic e e	5	46	56	+10
		Heat Sealed Woven Dacron				
457	157	Aorto iliac shunt	9	12	12	0
263	205	Aorto iliac shunt	10	74	70	− 4
		Elasticized Dacron				
7	157	Aorto iliac shunt	9.5	13	11	− 2
416	175	Aorto iliac shunt	9	36	48	+12
418	186	Aorto iliac shunt	9	28	28	0
365	0	Aorto iliac shunt	10	13	13	0
		Glass Tube				
158	0	Abd aortic e e	8	25	30	+ 5

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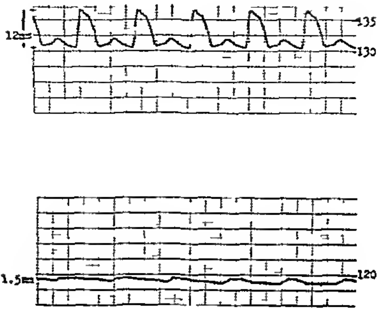

Fig 8 Transmission of pulse pressure through a canine autogenous venous shunt graft as measured by an electronic recorder *above* proximal to the graft and *below* distal to the graft. This graft and its anastomosis grossly appeared to be excellent The diminution of distal pulsation caused exploration of the anastomosis and removal of unsuspected clot following which the distal pulsation became similar to the proximal one shown above

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Chapter III

CLINICAL BACKGROUND OF VEIN GRAFTING

ALTHOUGH AUTOGENOUS vein grafting had been performed successfully prior to the past decade, modern technics are considerably different and by-pass shunting has largely replaced end-to-end grafting. While early experiences indicated the feasibility of vein grafts, they are not completely pertinent to the modern problem of by-passing atherosclerotic peripheral occlusion.

The discovery of the anticoagulant heparin led Murray to use this clinically and in 1940 he reported successful autogenous venous replacement of a popliteal aneurysm.[26] Two and a half weeks later a small aneurysm which had developed in the wall of the transplanted external jugular vein was repaired and there had been no further difficulty at the two-year follow up.[26] In 1952, he reported that 4 vein grafts had been satisfactorily in place for over 11 years.[27] In 1951 Kunlin[19] reported 7 long-term successes of 17 long autogenous vein grafts placed as shunts for atherosclerotic femoral occlusion. This series included 6 early failures (with 2 patients dead and 2 anastomotic leaks requiring ligation) and 4 later failures, but clearly demonstrated the feasibility of end-to-side anastomoses between long reversed vein grafts and the femoral and popliteal arteries.

Shaw and Wheelock[35] in 1955 reported considerably better initial success with homologous arteries (11 of 13 patent) than with autogenous veins* (5 of 13 patent). Shaw in 1958[31] discussed the long term performance of short peripheral vein replacements and reported that four-year studies of 5 vein grafts indicated that 4 were still open while five-year studies of 9 of the arterial homografts showed that only 1 was still open. On the other hand, he had had poor success with long venous grafts. Linton[20] in 1955 compared his experience to that date with both autogenous and homologous veins and homologous arteries used as peripheral shunt

*One of these was an homologous vein graft.

grafts and stated that 61% of the 13 autogenous veins had remained patent Despite numerous advantages enumerated by him, he recommended the vein grafts particularly for short replacement

Julian [14] and associates [6 15 16] emphasized selection of patients and progression of disease and reported that early failure had followed in 40% of their 30 vein grafts with 6 other late failures This series consisted of homologous as well as autogenous vein grafts and some patients had associated endarterectomy Kautzky and Brussatis [18] reported 70% patency in 46 grafts after a year and 50% patency after 3 years, but Rob [31] in the same year expressed dissatisfaction with autogenous vein grafts and indicated his preference for homologous arterial grafts

Lord and Stone [22] in 1957 reported that 16 of 21 vein grafts had remained patent and particularly noted that 100% of 12 placed into a vascular tree whose periphery was widely patent (trauma, tumor, aneurysm or fistula) had remained open but that only 4 of 9 placed for atherosclerosis had continued to be patent However, they continued to believe that venous grafts are inherently satisfactory for peripheral reconstruction and later stated that these had remained patent without aneurysmal dilatation for as long as 7 years in their experience [23] Fontaine [8] in discussing Lord s series stated that 2 of about 60 vein replacements for aneurysm failed whereas of those done for occlusive disease one third had failed early and another 25% had failed later He further reported 37% patency of 174 cases done for segmental sclerotic disease 3 to 9 years earlier and pointed out that the disease itself influenced the result In the same year, Deterling [5] editorially expressed the view that while 'results with synthetic replacements has still not been as good in peripheral arteries of patients suffering from arteriosclerotic occlusion as with *homologous arterial* or *autogenous venous grafts* ' that the results with long venous replacements for segmental occlusion have been far inferior to those enjoyed with arterial homografts '

The results of short venous autografting for lesions where the peripheral circulation was quite patent again proved to be good in the Korean War vascular experience as reported by Hughes [12] and Jahnke [13] who found no evidence of aneurysm formation in short grafts which had been in place up to 5½ years postoperatively

TABLE VI
SUMMARY OF RECENTLY REPORTED CLINICAL SERIES OF AUTOGENOUS VENOUS GRAFTS
Arrow indicates all failures shown as early

Author	Year	Type Anast	No. and Lesion	Failures Early	Failures Late	Successes	Postoperative Clinical Vein Graft Follow up: Arteriograms	Aneurysms	Comments	Time
Murray (26)	1940	E E	2 aneurysm 1 trauma	0	0	3		1 (later repaired)	short replacement grafts	to 1 yr
Murray (27)	1952	E E	1 femoral	0	0	1		none	long follow up	11 yrs
Blakemore Lord (1)	1945	E E	2 trauma 2 AVF	1	0	3	no dilatation	none	non suture technic	to 7 mos
Rose Hess Welch (33)	1946	E E	8 trauma	5	?	22			non suture of war wounds	short
Shumacker (36)	1948	E E	6 aneurysm	1	0	5				1 3 mos
Freeman Shumacker (9)	1955	E E	6 trauma	1	0	5			no dilatation	1 11 mos
Kunlin (19)	1951	shunt	17 a s	6	1	7	large but stable		2 died and 2 ruptured	2¼ yrs
Julian Dye Olwin, Jordan Grove Javid (6, 14 15 16)	1952 1956	E E	30 a s	10%	6	40%	some dilatation	1 small	includes homologous vein grafts and associated endarterectomies	to 5 yrs
Malan (21)	1953	E E	4 a s	2	0	2			3 heparin hematomas	?
Conley (2)	1953	E E	9 neck tumor	1	0	5			placed in irradiated infected necks	5 mos
Hughes, Jahnke (11, 12)	1953 1958	E E	17 AVF & aneurysm	?	?	?	no dilatation	none	traumatic AVF and aneurysms	to 5½ yrs

Jahnke (13)	1958	E E	19 trauma 8 failure— 10 graft	9 0	0 0	10 8	no details		Korean War injuries	?
Pratt, Krahl (30)	1954	shunt	26 a s	?	?	?			10 good pulse 8 amputation	?
Pratt (29)	1958	E E or shunt	22 a s	?	?	?				?
Linton (20)	1955	shunt	13 a s	5	←	8				?
Shaw, Wheelock (34, 35)	1955 1958	shunt	13 a s	8	1	4			1 homologous vein used	4 yrs
Hoye, Warren (10)	1956	E E or shunt	13 a s	1	7	6	some dilatation			2 5 yrs
Kautzky Brussatis (18)	1956	shunt	46 a s			70% 1 yr 50% 3 yr			good analysis	to 3 yrs
Rob (31, 32)	1956 1957	? E E	25 a s	15	←	6			4 died	to 18 yrs
Fontaine (8)	1957	?	60 aneurysm 174 a s	2 33%	0 25%	58 37%			better results if distal vessels open well	3 9 yrs
Lord, Stone, Cloutier, Breidenbach (22 23)	1957 1958	12 E E 9 shunt	5 trauma 6 aneurysm or AVF 1 tumor 9 a s	4	1	16		none	1 graft ruptured 41 p o d	to 7 yrs
Felder, Murphy (7)	1958	shunt	45 a s 9 popliteal aneurysm	13	←	40				5 24 mos
Hitchcock, Johnson Bascom, Murphy (17)	1959	shunt	11 a s 32 a s	4 5	← ←	7 27			aorta iliac to femoral femoro popliteal shunts	? ?
Dale DeWeese, Scott (1)	1959	shunt	31 a s	10	3	18	7 no dilatation	none	author s series	to 13 mos

These clinical experiences indicate some difference of opinion as to the merits of long autogenous vein grafts used to replace atherosclerotic occlusion yet increasing experience appears to have resulted in a slow increase in their popularity as confidence in homologous arterial grafts has waned and as doubts of the long term results of synthetics has occurred Nyhus and Harkins[28] in 1957 indicated preference for autogenous saphenous vein plastic tube and arterial homograft in that order Linton[21] in 1958 listed his order of preference for reconstructive surgery of femoral occlusive disease as (1) autogenous saphenous vein grafts (2) thromboendarterectomy (3) combination of thromboendarterectomy and saphenous vein grafts (4) arterial homograft and (5) synthetic prostheses

A thoughtful survey of 178 patients having various shunting operations with several types of grafts was reported in 1959 by Hitchcock Johnson Bascom and Murphy[3] from Minneapolis General Hospital Their best results by passing the femoro-popliteal artery were with autogenous veins (84% patency) but extension of criteria for operability may have been reflected in the crimped nylon series (63% patency) Their comparative experience is of value since most reports are devoted to a single material

Earlier fears that autogenous vein grafts would often form aneurysms have not proved justified Table VI summarizes clinical series reported recently in which only 2 aneurysms occurred So far as can be determined from the reports there was a success rate of approximately 56% of the 383 cases done for atherosclerotic indication but there was 81% patency for 127 done for non atherosclerotic indications The follow up times were variable. The survey indicates the difference in outlook relative to the underlying disease for which the graft was placed It also emphasizes the need for careful follow ups of such patients to determine late as well as early failure rates

Personal Experience

The results of the initial 31 consecutive autogenous venous grafts to by pass atherosclerotic femoral occlusion are summarized in Figure 9 modified from our recent report[4] Indicated follow up

times are to the last actual clinical examination and do not necessarily show total postoperative time This series is consecutive and includes patients with good as well as poor outlooks The prognosis as judged by the arteriogram is indicated in the fourth column where I indicates excellent vascular reconstitution with uniformly patent branches II indicates reconstitution with absence of a branch or branches of the popliteal artery or quite evident scalloping and narrowing and III indicates absence of distal reconstitution Only one case fell into that category and it is included in the series because a graft was actually placed

Failures

Six of the vein grafts thrombosed in the immediate postoperative period Aside from the one expected failure described above there was no uniform explanation for the other failures but it was thought that they represented technical operative errors Seven of the initially successful vein grafts failed being patent for at least 48 hours Two of these were associated with poorly drained wound infection going on to bleeding from a suture line and requiring ligation of the graft Another patient had a distal endarterectomy for a particularly severely diseased popliteal vessel and it is thought that recurrence of thrombosis in that area resulted in failure of the graft The other two failures occurred at four months and 12½ months respectively The latter occurred in a graft which had remained patent above a mid calf amputation and it is thought finally represented lack of distal blood flow

The 18 grafts patent at last examination require no further comment but clearly require prolonged follow up study

Amputation

Of particular importance is the relation of direct arterial surgery to loss of the extremity in the postoperative period Analysis of this clinical series indicated that all of the six amputations had been impending prior to arterial grafting In two patients it was thought that the amputations were hastened somewhat by failure of direct arterial surgery but the other four had no particular change in their course although failure of the graft resulted in amputation some

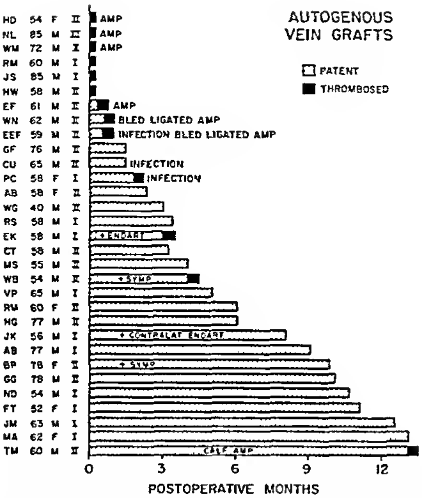

Fig. 9 Initial 31 consecutive femoro-popliteal vein grafts for atherosclerotic occlusion. Follow up time is to last actual examination. "Infection" shows wound infection.

time in the postoperative period. Study of the overall series leads to the belief that this form of direct arterial surgery does not cause great hazard to the extremity should it fail and results in great salvage in terms of function and tissue viability when successful.

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PERIPHERAL VASCULAR INSUFFICIENCY

ARTERIOSCLEROSIS *is the most* common cause of peripheral vascular insufficiency while peripheral arterial embolism, arteriovenous fistulas and aneurysms, tumors and trauma less commonly threaten the function or viability of the extremity In lesions such as atherosclerotic occlusion where complete removal is not mandatory, by pass shunt grafting had several advantages over resection with end to end replacement and this discussion is in general directed toward this entity although much of it is also true of less common causes of vascular occlusion

Pathophysiologic Concepts

Understanding of function to date lags behind pathologic and anatomic studies The development of microscopic methods of blood flow study [5] and of clinical flow meters [2,10] promise new information on mechanisms which are poorly understood at present and which seldom go beyond the belief that high degrees of vascular luminal obstruction occur before much actual decrease in blood flow results Explanation of this on the basis of Poiseuille's law allows understanding of the importance of small changes in the lumen of the artery but is an over simplification of considerably more complicated rheologic principles [5]

Burton's [1,9] concept of "critical closing pressure" and his demonstration of the luminal closure of vessels prior to reduction of internal pressure to zero has clinical implications in relation to development and maintenance of collateral circulation through which low pressure flow occurs

Full discussion of these concepts and others including the role of the several factors in peripheral vasomotor mechanisms are beyond the scope of this and reference is made to more detailed physiologic studies

Pathology

The vascular changes occurring in arteriosclerosis are localized (although they are often widespread) and continued use of the

term "generalized" arteriosclerosis is to be avoided because of its connotation of equal involvement of arteries in all parts of the body. Actually there are invariably many arteries which show considerably less change than other localized areas do The segmental nature of the disease should be emphasized.

The term arteriosclerosis" includes several types of degenerative disease of the arteries which require brief definition. In particular should be contrasted *medial arteriosclerosis* (characterized by fibrosis, areas of necrosis, calcification and occasionally bone formation in the media of the artery) with *atherosclerosis of the intima* (in which there are lipid deposits beneath the endothelium) which tends to enlarge and frequently goes on to arterial thrombosis either because of the extensive narrowing of the lumen or because of ulceration of one of the atherosclerotic plaques Medial arteriosclerosis in rare cases may result in arterial occlusion but ordinarily does not of itself (although it may coexist with intimal atherosclerosis)

In particular, it should be noted that the symptoms of peripheral vascular disease are due to arterial thrombosis complicating a form of arteriosclerosis and not to arteriosclerosis per se. This arterial thrombosis may result in a clinical situation mimicking peripheral arterial embolism but more often is gradually noted as easy fatigability and claudication in the distal muscles such as the calf where sufficient blood flow through collaterals allows relatively good extremity nutrition at rest.

Sites of predilection of atherosclerotic occlusion include the cerebral and the coronary arteries as well as the vessels of the lower part of the body Upper extremity lesions are most unusual. The difference between incidence in upper and lower extremities is clearly defined but the basic reason is poorly understood. Studies of atheromata with secondary thrombosis causing occlusion indicate that the most common site is in the femoro-popliteal arterial tree originating at the point where the superficial femoral artery passes down through Hunter's canal in the adductor magnus muscle to form the popliteal artery The next most common site of atherosclerotic and thrombotic occlusion is in the distal aorta and iliac arterial system Lindbom's [7] arteriographic studies of 295 legs of

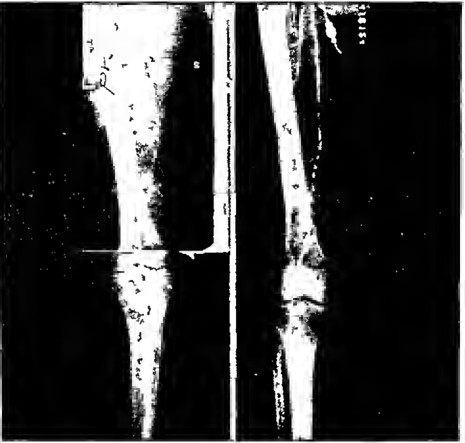

Fig 10 Progression of atherosclerotic occlusion in the superficial femoral artery *Left* the initial arteriogram shows a double short block at the hiatus in the adductor magnus muscle with minimal scalloping and irregularity of the more proximal artery *Right* shows considerable increase and scalloping and irregularity and further occlusions 9 months after the first arteriogram

patients and cadavers established the highest incidence of occlusive disease at the adductor magnus hiatus with decreasing incidence in both directions from that

Mavor s[8] series of 149 consecutive cases of atheroma with secondary thrombosis showed that 85% were located in the femoral artery and that all except two of those originated at the adductor magnus hiatus Figure 10 (on the left) illustrates an early lesion and (on the right) its later development as shown by arterio

graphy. Proximal superficial femoral arterial involvement without distal involvement occurred only twice in the Mavor series and was therefore distinctly unusual. He stressed the importance of the profunda femoris as a main collateral since it rarely thromboses. The reason for its immunity is unknown. Lower leg atherosclerosis commonly affects the posterior tibial artery prior to and more severely than others.[1]

The reason for this localization is not clear although it has been suggested that there are mechanical anatomic reasons.[3] Lindbom[7] stressed the frequency of intimal hemorrhages in association with thrombosis at atherosclerotic areas.

The existence of thromboangiitis obliterans (or Buerger's disease) as a separate entity has been recently questioned to a considerable extent.[4,6,8,11] Prior to the post war interest and development of peripheral vascular surgery, patients developing arterial insufficiency of the distal lower extremities were usually diagnosed as thromboangiitis obliterans if they were relatively young and as arteriosclerosis obliterans if they were older. That age alone is not a proper diagnostic criterion is well recognized now with diagnoses of presenile or juvenile forms of atherosclerosis and secondary thrombotic occlusion being recognized frequently. The incidence of Buerger's disease has therefore declined since more patients are now being classified as some form of arteriosclerosis.

There is doubt that a patient with main vessel disease as well as arteriolar disease can justifiably be classified as thromboangiitis obliterans and increasing belief that cases of thromboangiitis obliterans usually represent variants of arteriosclerosis. Clinical examples of arterial disease outside the arteriosclerotic group (or other recognized groups) which can be classified as Buerger's disease are unusual. Arteriographic, operative or autopsy evidence of atherosclerosis usually occurs with time to refute the original diagnosis.

Clinical Syndrome

The *history* of peripheral vascular insufficiency usually centers on pain. The complete absence of pain raises doubt that much occlusion has occurred although it is recognized that the occasional

patient ceases activity upon a feeling of fatigue and that the true pain of muscular claudication is never reached Whether muscular claudication pain is primarily due to failure of clearance of metabolites or to some other mechanism has never been completely resolved but from the practical viewpoint this symptom signifies failure of the blood supply to meet the needs of muscular activity Claudication upon exercise with a distal extremity which is properly nourished at rest strongly suggests main vessel femoro popliteal occlusion with collateral sufficient to meet the need until muscular exertion occurs Pain at rest usually signifies collateral which is insufficient either from failure of development or from secondary failure due to disease

Not only is the type and severity and provocation of pain of importance in arriving at a clinical diagnosis but also the mode of onset (which may indicate acute thrombosis or peripheral embolism contrasted to the usually slower onset of more gradual atherosclerotic thrombosis) and also the location by which the level of occlusion may be judged Calf pain signifies distal superficial femoral arterial occlusion while antero lateral lower leg pain suggests anterior tibial arterial occlusion and thigh and buttock pain suggest iliac and aortic occlusion respectively Coldness and color changes are historically less reliable in determining the lesion from the patient s symptoms alone

Physical examination is initially directed toward palpation of the peripheral pulses not only in the aorta and femoral arteries but also in the popliteal dorsalis pedis and posterior tibial vessels Clinical gradation of these from 0 to 4+ (for normal pulsations) stresses the importance of continually attempting to evaluate the normality or abnormality of each palpable pulse Care in proper evaluation is mandatory since haste may lead to interpretation of the examiner s pulse as that of the patient or to overlooking a diminished pulsation completely While an experienced examiner may approach the *oscillometer* in accuracy the latter offers a readily available means of assessing the distal pulsations in terms of units which may be easily recorded It is also useful when bandages or lesions make pulse palpation difficult or impossible

Elevated exercise of the lower extremities by plantar flexion

and dorsiflexion of the feet furnishes a simple stress test of the blood supply to the lower extremities. The elevated position should be maintained for several minutes and color and capillary return examined only at the end of that time. Actual walking or walking in place may cause pulse obliteration to indicate otherwise unsuspected proximal arterial disease.

Unless there be a marked temperature change, this is of little clinical significance but it may be of some value if *skin thermometry* is used *Nail changes* and *loss of hair, venous pathology* and the occasional *murmur* and *thrill* should not be overlooked.

Various degrees of pregangrenous and gangrenous changes as well as acute inflammatory evidences are common findings and suggest failure of collateral as well as main vessel circulation.

Clinical tests of walking to the point of claudication are often useful to corroborate historical symptoms although it is recognized that claudication distance is a poor objective test. Skin temperature studies related to *plethysmographic* blood flow estimations may be of interest although their importance to ordinary clinical management is doubtful Other tests with *isotopes, ergographs,* and *colorimeters* are known but at the moment are not of great clinical importance

The majority of cases of peripheral vascular insufficiency can be clinically appraised by a proper history and simple office examination with a fair degree of accuracy but require angiographic mapping to ascertain definitely the extent and level of the lesion. This may also be of importance in absolutely ruling against vascular disease in the presence of symptoms of neurologic or orthopedic lesions and is discussed in the following chapter.

Illustrative Case

A 62 year-old white female had a history of two years increasing calf claudication after one to two blocks. Pulses were absent distal to the femorals bilaterally Femoral arteriogram showed a distal superficial femoral block of the right superficial femoral artery with patent distal vessels (Figure 11a)

An autogenous venous shunt graft was placed between the common femoral and distal popliteal artery with immediate

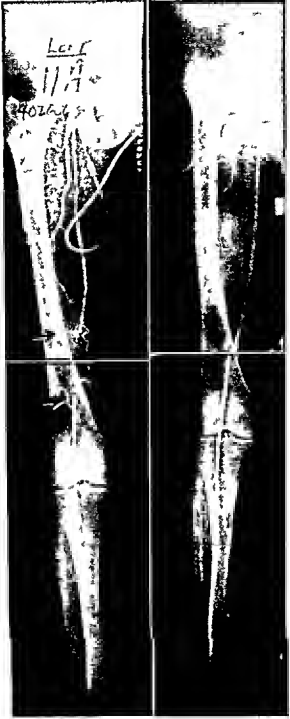

Fig 11 Pre and postoperative arteriograms (a) Short superficial femoral block with distal reconstitution (b) Patent autogenous venous shunt graft 13 months after operation The superficial femoral artery has gone on to complete thrombosis since the graft was placed

return of oscillometric pulsations in the calf and with good distal pulses Her convalescence was uneventful and she returned to work without symptoms

Femoral arteriography was again performed 6 months after operation and showed complete graft patency Twelve and a half months after operation she was still asymptomatic. A femoral arteriogram (Figure 11b) showed patency of the venous shunt graft 13 months after operation She continued to have two block claudication in the *unoperated* left leg

Comment This represents a typical candidate for a shunt graft because of symptoms decreasing her ability to work and an arteriographic pattern indicating a good distal run-off circulation Two postoperative arteriograms have confirmed patency of the graft and she is asymptomatic on that side The contralateral symptomatic extremity should now be repaired

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Chapter V

ARTERIOGRAPHIC EXAMINATION

WHILE A PROBABLE clinical diagnosis can often be made on the basis of history and physical examination the use of readily available x ray technics allows visualization of the peripheral arterial tree with accurate delineation not only of complete occlusion but also of lesser lesions in non-obstructed portions of the arteries Knowledge of the involvement of these not yet obstructed arterial regions is often important to the proper decision regarding both short and long term therapy Thus it becomes of extreme importance to add to the clinical diagnosis information obtained by suitable angiographic examination Such suitable examination has been expressed by Rogoff [14] as a conservative balance among the surgeon s need for information about the patient s vessels the radiologist s interest in good roentgenograms and the patient s right to comfortable survival following any diagnostic procedure along with a consideration of cost and convenience factors

Radiopaque Dyes

Many radiopaque substances have been developed for clinical arteriography since the early use of sodium iodide was reported by Brooks [4] in 1924 and with rapid developments progressing in this field it appears likely that current preferences may at any time be outmoded However for illustrative purposes the use of Hypaque will be discussed herein as the best and safest of currently available materials

Killen Lance and Owens [*] have showed the considerably less danger associated with Hypaque when injected either into renal artery or lumbar arteries of dogs Clinical experience to date corroborates this

Aortography

Increasing experience with aortography has led to the general conclusion that it is unduly risky unless there are pressing needs

for such examination and that peripheral arteriograms should be substituted wherever possible In the occasional case where abdominal aortography is mandatory it may be performed through a left postero lateral approach utilizing either spinal or general anesthesia Spinal anesthesia is preferable because an endotracheal tube must be placed if general anesthetic technic is used (since the patient will be lying face down and an adequate airway must be assured)

The needle is placed in the aorta distal to the renal vessels This slightly more difficult technic is safer than injection of dye proximal to the renal arteries Judicious use of test doses and interpretation of failure of entry of the needle as often indicating distal aortic thrombosis has allowed avoidance of injection of the more proximal aorta

Following induction of proper anesthesia, a long (six inch) 17 gauge needle is passed through the surgically prepared skin at a point about four finger breadths lateral to the mid line of the back and opposite the second lumbar vertebra The needle is directed at a 45° angle toward the body of the vertebra until this is contacted and then withdrawn slightly prior to passing the needle point just in front of the body into the aorta The needle is slowly pushed in with its stylet removed so that penetration of the aorta will allow blood to spurt from it Care should be taken that jabbing or rapid motions are not used and that the passage is made slowly to prevent transfixion of the aorta and passage of the point out the far side

After the needle has been properly placed within the aorta a plastic connecting tubing is used to attach a 30 cc syringe containing 50% Hypaque, and the radiologist makes any final adjustments which are needed A 5 cc test dose of Hypaque is then injected and the needle washed through with heparinized saline and the stylet replaced to allow development of the initial film which was exposed lying beneath the pelvis and upper thighs Examination of the film made after the 5 cc test dose will often provide enough information so that a larger bolus of Hypaque can be avoided

In the instance where peripheral femoro popliteal visualization is desired, a further dose is given (following the 5 cc test dose which serves to ascertain that the needle is properly placed and that dye

is not being forced rapidly into renal vessels or the mesenteric tree). After this precaution has been observed the actual bolus of 30 cc. of 50% Hypaque is injected as rapidly as possible and the first exposure made on either a single long film or two shorter films as the last 5 cc is injected

Serialization of films is important since the initial films often fail to show the distal run-off circulation [14] The change to the second exposure films can be effected in any of several ways but serial films should be made as rapidly as possible The needle should then be removed from the aorta because it is undesirable to inject further material into the aorta should the films be a failure

Femoral Arteriograms

Since aortograms are ordinarily contraindicated because of the hazards associated with them, the radiologic exploration of the peripheral vascular tree is ordinarily done by means of femoral angiography This may be performed simply using local anesthesia for percutaneous placement of a # 18 needle into the common femoral artery (pointed at a 45 angle from below upward) through which a bolus of 20 cc of 50% Hypaque may be rapidly injected

Here again serialization of films by one of several technics is important to the final understanding of the vascular pattern because early films may fail to show the slow passage of dye into the distal run-off circulation (Figure 12 shows the better distal arterial outline in film 3 compared to film 1) With the patient prepared for a period of about 15 seconds of burning pain in the lower extremity by instruction as well as by previous injection of Demerol®, there is ordinarily little need to use a general anesthesia The patient should be cautioned about the occurrence of burning pain and instructed to press the heels sharply against the table to prevent motion Following removal of the needle from the femoral artery firm pressure is made over this point for a minimum of 5 minutes to prevent hematoma formation

Following successful femoral arteriography on one side the other side may be similarly studied in order to evaluate properly the entire arterial tree of both legs prior to forming a plan of overall therapy

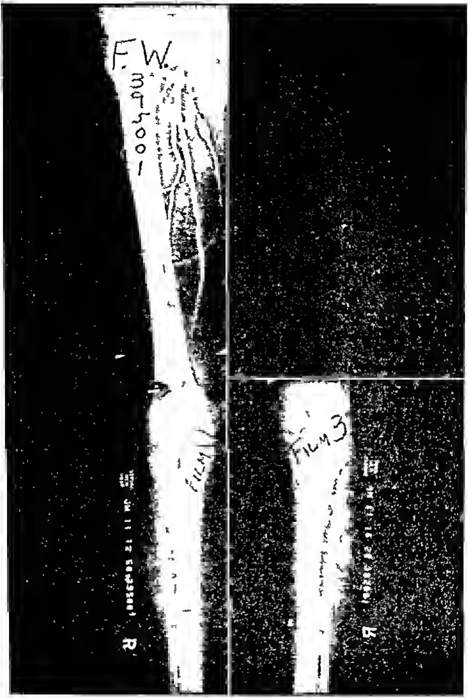

Fig 12 Demonstration of importance of serialization of arteriographic films Film 1 on *left* shows excellent detail of superficial femoral and popliteal arteries down to knee but a later film on *right* is important in showing details of the patent distal circulation

Illustrative Case

A 56-year-old male had bilateral calf claudication worse on the right with absent pulses there but with faint left-sided posterior tibial pulse. As Figure 29 on page 101 shows both legs were studied by arteriograms prior to operation Knowledge of the short occlusion of the less symptomatic left leg allowed it to be repaired (by endarterectomy) at the same operation.

Operative Arteriograms

In the event that percutaneous femoral arterial puncture is impossible or unsatisfactory, it is a relatively simple procedure to expose the femoral artery by a short longitudinal femoral incisinn in order to place a #18 needle within under direct vision, or to place a small polyethylene catheter through a #13 needle intn the lumen of the vessel In the latter event it may be necessary tn place one silk suture at the point of puncture to stop bleeding after removal of the needle

Despite some statements that proximal arterial occlusions should be made to prevent the rapid passage of dye distally, it has nnt ordinarily been necessary either to place a proximal tourniquet directly on the vessel or to make manual pressure, and the blood flow has been allowed to carry the dye distally withnut any proximal obstruction

Popliteal Arteriograms

The distal run-off circulation may be assessed by injection of radiopaque material directly into the popliteal artery at the time of its exposure through a low thigh incision when either endarterectomy [1] or shunt grafting is contemplated. Ten cubic centimeters of 50% Hypaque may then be injected either via a needle or small polyethylene catheter into the popliteal artery (Figure 13) This allows a splendid arteriogram to be made of the distal run-off circulation but gives no information about the arterial tree between common femoral (where it is surgically exposed if a graft is to be placed) and the popliteal exposure. It is recognized that if a shunt graft is placed between common femoral and popliteal artery that no exact knowledge of the intervening superficial femoral

Fig. 13. Operative popliteal arteriogram using 10 cc. of 50% Hypaque injected via polyethylene catheter through arteriotomy into the popliteal artery just prior to placement of a shunt graft.

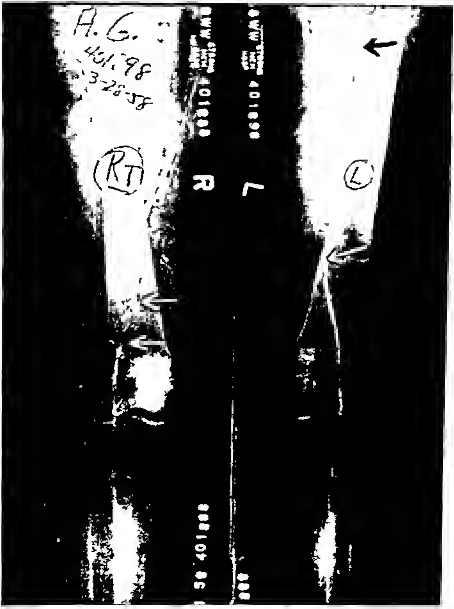

Fig. 14 Bilateral femoral arteriograms illustrating relatively short popliteal block on the right and considerably longer superficial femoral block on the left. Bilaterally the distal circulation is reconstituted well and the outlook for bypass grafting should be good.

artery is really necessary It is however believed profitable to be able to study the peripheral circulation at whatever length is necessary prior to determining therapy and it is for this primary reason that arteriograms are ordinarily obtained prior to operation rather than at the time of operation If they are to be obtained prior to operation percutaneous femoral arteriograms therefore have considerably more use than do operative popliteal arteriograms

Interpretation of Arteriograms

Each arteriogram must be studied in the light of clinical history and physical examination and other laboratory data In general peripheral arteriograms may be divided into three categories In Figure 14 is shown an illustration of a patient classed as an excellent candidate for shunt grafting from an arteriographic standpoint There is excellent reconstitution of the popliteal artery and its distal branches are well filled Arteriographically the distal run off circulation does not appear to be greatly involved by atherosclerosis since there is no major scalloping or narrowing but it should be recognized that the operative findings always show more involvement than is recognized from x ray study

The second category is illustrated by Figure 15 in which there is dye apparent in the popliteal circulation but in which there is also irregularity and loss of one or more of the distal branches This group may be acceptable for shunt grafting provided there are strong clinical indications otherwise but may not have as good long term outlook as the first group because their atherosclerotic disease is greater

Patients without adequate distal circulation are classed as not acceptable for shunt grafting Figure 16 illustrates the (operative) arteriographic appearance of such an extremity where serial arteriography has failed to demonstrate any main vessel patency at the popliteal or more distal level Earlier hopes that actual operative exploration might demonstrate a patent vessel which failed to visualize by arteriography have not been borne out and surgical exploration in such instances has largely been abandoned as in general being productive of poor results and a high complication rate which may be avoided by conservative non surgical measures

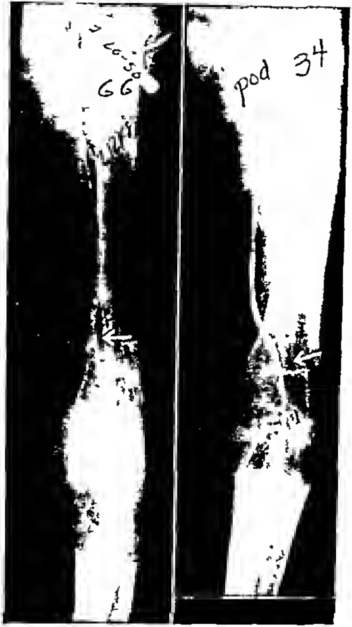

Fig 15 Pre and postoperative arteriograms illustrating compromised distal reconstitution of arteries. (*Left*) A long superficial femoral arterial occlusion with distal popliteal reconstitution but with occlusion of the distal vessels at the popliteal bifurcation (*Right*) Patent autogenous venous graft 34 days after operation with distal flow through collaterals Arteriographic examination indicates a guarded prognosis after grafting but other clinical considerations led to placement of the graft which has functioned well during the ten month postoperative follow up to date

Fig 16 Operative femoral arteriogram shows long femoral arterial occlusion with failure of distal reconstitution Arteriographic examination indicates no reasonable hope for a successful shunt graft and operative failure confirmed this.

The clinical situation often determines the final recommendation for therapy even more than the actual arteriographic examination and may cause a patient to be moved from one group to another or cause tentative advice to be changed. Adequate x-ray visualization of the vessels should however be available prior to definitive advice to the patient.

Hazards of Angiography

The chief hazards of angiography are enumerated briefly below. In general it may be said that these are more to be feared following aortography than after femoral arteriography. Except once no complication more serious than extravasation and for hematoma formation in the femoral area has occurred in our hands. However, several of the complications mentioned below have been seen elsewhere or reported elsewhere or have been discussed with others and must certainly be guarded against.

1. *Renal damage* may follow direct dumping of high concentrations of hypertonic iodinated compounds either from the aorta directly or by needle into one or both renal arteries.[*] Stokes and Butcher[14] surveyed 1298 reports of aortography from seven series and found 0.8% mortality to be chiefly due to renal injury. This may result in either temporary[11] or irreversible renal damage. There is evidence that this effect may be decreased considerably by attention to hydration prior to aortographic examination.[3] The use of a test dose prior to injection of the complete bolus of radiopaque material should alert the examiner to this possibility before it happens.

2. *Bowel damage* due to injection of the material into the mesenteric vascular system may similarly occur and should be similarly prevented by proper attention to the test dose pattern.[1*]

3. *Transverse myelitis* with paraplegia has occasionally occurred. Crawford, Beall, DeBakey and Moyer found 13 reported cases in 1957 of which 12 died.[*] Its incidence has probably been over-emphasized by its tragedy. None occurred in the 1298 aortographies surveyed by Stokes and Butcher.[14] Distal aortic injection and small doses are thought to minimize this risk. The experimental incidence of this has been greatly decreased with the use of Hypaque rather than previous radiopaque materials.[*]

4 *Intravascular thrombosis* has not been widely recognized but appears to be a problem worthy of consideration in the patient whose distal aorta is partly or completely occluded at the time of examination Injection of the irritant hypertonic radiopaque material above an occluded site and into an area of stagnant blood may result in a rapidly increasing thrombosis above the old thrombus previously and may result in propagation up to include important proximal vessels such as the renal arteries In more than one instance where aorto iliac occlusion of the aorta has led to aortic resection for Leriche syndrome very fresh intraluminal thrombus has no doubt been due to the aortogram performed a few days prior to operation In one recent instance where only a 5 cc test dose of material was placed into the aorta a soft thrombus formed and remained proximal to the occluding clamp placed for distal endarterectomy Five hours after endarterectomy and resuture of the aorta, this soft attached thrombus dropped down into the aortic bifurcation as a saddle embolus and required secondary operation for its removal Thrombosis at the site of puncture may occur in a more distal vessel also and require operative removal or even an immediate by pass graft [6]

5 Local *damage to the arterial wall* of the femoral artery may occur if it is improperly handled For instance, one patient was seen following an open arteriogram where bleeding had led to temporary clamping of the femoral artery with the necessity for resection and grafting because of damage by this clamp Wolfman and Boblitt [17] have commented upon the changes of intra mural aortic injection, reporting four deaths in a group of 33 such (of a total of 302 aortograms)

6 A *plaque* may be dislodged at the point of entrance of the needle and carried peripherally to act as an embolus and result in an acute vascular occlusion Similarly, such a plaque may simply be elevated and cause occlusion of the femoral vessel as blood dissects behind it at the site of its elevation

7 *Hematoma* may result locally from the point of puncture Ordinarily it is of no clinical importance, but an occasional death has occurred after aortic leak [10 12] Operative exposure of the femoral artery following an arteriogram often shows thickening and a moderate degree of chronic inflammation of the adventitia of the

vessel as evidence of the previous trauma and hemorrhage Some degree of retroperitoneal hemorrhage is no doubt a constant accompaniment of aortography In each instance where the aorta has been explored within a short time after aortography minor to moderate degrees of retroperitoneal hemorrhage have been found This bleeding and consequent dissection probably explains the back ache which a number of patients have following the injection

8 *Extravasation of dye* may follow passage of the needle completely through the vessel or occur by withdrawal of the needle from the lumen prior to complete injection Severe pain at the site of injection suggests this and the need for local anesthetic injection Skin sloughs are reported [9] but fortunately are rare after such Immediate dilution with procaine is recommended for relief of pain

9 *Drug sensitivity* has not been personally observed although it is known [6] Premedication with barbiturate and availability of stimulants is in order as well as routine testing with small skin doses of the drug prior to the final angiographic injection The occurrence of reactions despite negative skin tests should be recognized [13]

10 *Peripheral Circulatory Collapse* Shock syncope or vasomotor collapse may be rarely encountered The only two such personally observed experiences occurred consecutively on the same day following extravasation of 50% Hypaque during an attempt at aortography and immediately thereafter in another patient during an attempt at femoral arteriography In each instance there was severe local pain and this was immediately followed by nausea and faintness In the patient whose femoral artery was extravasated there was vascular collapse with loss of consciousness and temporary cessation of cardiac beat which was restored by two sharp blows on the precordium Both of these patients had been previously tested for dye sensitivity and the reactions were thought to be neurogenic in origin

11 *Miscellaneous* Thoracic duct injury with necessity for thoracotomy to control chylothorax has occurred

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Chapter VI

CHOICE OF GRAFT MATERIALS

THE CHOICE of a material for peripheral shunt grafting will necessarily reflect the experience and background of the surgeon. Ideally one should have at his command whatever material appears proper for the individual situation. Table VII summarizes clinically important characteristics of currently available grafting materials (without attempting to differentiate between the various synthetics).

TABLE VII
SUMMARY OF CHARACTERISTICS OF PRESENTLY USEFUL MATERIALS FOR PERIPHERAL VASCULAR GRAFTING

	Homologous Artery	*Synthetic Tube*	*Autogenous Vein*
Availability	often difficult	excellent	good
Technic	easy	occasionally difficult	difficult
Early patency	good	good	good
Late patency	decreases		good
Degeneration	yes	may weaken	no
Viability	no	no	yes
Resistance to infection	poor	encourages	good
Graft bleeding	no	yes	no
Antigenicity	rare	no	no
Pulse transmission	good	good	good
Reported experience	many recent	many recent	few longer time
Individual experience	?		

Availability

Synthetic tubes, of course, offer the most widespread availability and storage in varied sizes and shapes and obviously out-class both homologous arteries and autogenous veins in this respect. Difficulties in obtaining and maintaining supplies of homologous arteries has limited their use to large vascular centers. Despite fears that autogenous veins would often not be available or suitable, such *have occurred only three times to date. In one instance the patient* was found to have a completely fibrosed vein and an homologous arterial transplant was used instead. Another elderly lady had an extremely small saphenous vein which branched into two still smaller tributaries about six inches distal to the sapheno-femoral

junction Since this vein was considered non suitable because of inadequate size, a crimped teflon graft was used A third patient operated upon following failure of a crimped dacron tube elsewhere was found to have a small fibrotic saphenous vein as a result of phlebitis (probably occurring at the time of previous operation) Since it was considered unsuitable, the shunt was successfully performed with a crimped teflon tube * In such instances, it may be possible to use the contralateral saphenous vein

The autogenous vein of choice is the saphenous and so comes in only one size for each individual Use of femoral vein is contraindicated because of likelihood of deep venous thrombosis of the calf with subsequent difficulties The same was seen in the few animals in whom femoral veins were removed

Ease of Surgical Technic

In the experience of the author, an arterial homograft is the easiest material with which to shunt a peripheral vessel Some of the synthetic tubes are just as simple to manage during the anastomosis, particularly those which are knit and do not ravel nor require heat sealing Difficulties with bleeding will probably be controlled soon, as more information is gained about the optimal porosity of synthetics Undoubtedly, the autogenous venous graft is the most difficult to place from the technical standpoint because of the delicacy with which this thin walled, floppy material must be managed Even after considerable experience has been acquired with homologous arteries and synthetic tubes, it is necessary to refine technic to permit successful autogenous venous anastomosis to be made Animal experience has been helpful as a preliminary to clinical use

Dissection incidental to removal of the vein for use as a graft necessitates somewhat more operative trauma to superficial tissues than do either homologous arteries or plastic tubes

Early Patency

High percentages of immediate patency occur with autogenous veins, homologous arteries and synthetic tube grafts Since other disadvantages rule strongly against further use of arterial homo

*By Dr H William Scott

grafts, their patency results are not discussed in detail here. Synthetic tubes have been quite successful in terms of immediate patency. DeBakey, Crawford, Cooley and Morris [4] in 1958 reported 86% of 110 peripheral crimped nylon grafts to be patent and 89% of 137 crimped dacron tubes to be patent. Edwards and Lyons [6] reported 71% patency of 38 crimped nylon and teflon (7 early and 4 late failures). Julian, Deterling, Dye, Bhonslay, Grove, Belio and Javid [12] had only 7 failures in 54 femoro-popliteal by-passes (followed to 9 months) using their micro-crimped dacron tubes. Similar results have occurred elsewhere.

The early results with autogenous veins have also indicated a high patency experience, once the more difficult technic has been mastered. Because of this, it seems likely that initial experiences will not properly reflect later ones in most instances.

Late Patency

It is increasingly recognized that the patency percentage of homologous arterial grafts has decreased with increasing time of follow up studies.[15] Figure 17 summarizes 37 consecutive arterial homografts reported by DeWeese, Scott and the author.[2] Only 10 of these were patent at last follow-up. The 12 grafts which became occluded after a minimum of 5 months patency were generally ascribed to progression of disease although this was not proven in most. The overall results are not enviable yet to a considerable extent reflect the experience of others using homografts. Whether the poor results are due primarily to progression of the primary atherosclerotic disease of the host vessel or to degeneration of the homologous artery is not completely clear although the latter is increasingly reported.

Various analyses of series of homologous arterial grafts show complications peculiar to the material itself. Humphries, Hawk, deWolfe and LeFevre [11] in reporting 525 homografts for both large and small vessel replacement classified 10 deaths as due to technical failure and noted 6 aneurysms in the 33 grafts examined microscopically later as well as one instance of dissection. Foster, Lance and Scott [7] attributed only 2 complications to the homograft in 110 instances and found no aneurysms. Szilagyi [18] in discussing

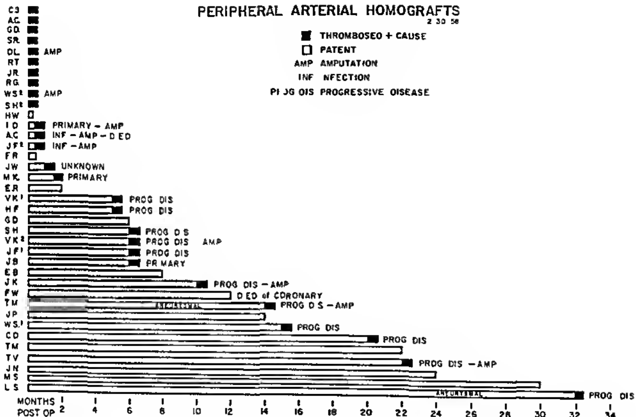

Fig 17 Thirty seven consecutive peripheral shunt grafts for atherosclerosis using homologous arteries Post operative follow up indicates time when last examined and not the total time since operation (Courtesy *Surgery* 46 115 1959—Dale DeWeese and Scott)

follow up studies of 270 homologous arterial grafts reported that there commonly was a structural change in femoral transplants after 2 years and that after 3 years only about 1/3 of the grafts appeared intact Barnes Ellis Kirklin and Edwards[1] considered that 10 deaths (of their 17 deaths in 165 cases of homografting) were due to failure of the graft Hershey Trump Solomon Wright and Joseph[1] reported 16 freeze dried and 154 freeze irradiated homografts with seven complications probably due to graft processing

The 90 consecutive arterial homografts studied by DeWeese Woods and the author[2] showed an 8 9% failure rate directly attributable to the material itself The eight complications were as follows

Aneurysm in graft	3
Rupture at site of tied branch	1
Fistula between graft and bowel	2
Infected graft leading to septicemia	1
Primary graft thrombosis	1

This with the experience of others leads to the conclusion that there are difficulties inherent in homologous arterial transplants which may be avoided using other materials

The late results of synthetic tube grafting are poorly reported to date Edwards and Lyons[8] longest reported follow up of crimped nylon and teflon was 2 years 10 months DeBakey s group[4] found that 14% of their patients leaving the hospital with patent grafts had later become occluded The late failure rate varied with the type graft and was 18% for homografts 21% for crimped nylon and 6% for DeBakey crimped dacron (the latter a newer material followed less time) While many studies of various materials are reported to show excellent immediate patency rates there is a great need for a long term follow up of all these materials Whether the large luminal diameter of currently used synthetics and large anastomoses will overcome the disadvantage of the considerably thicker neo-intima deposited inside a synthetic tube and allow prolonged late patency is not fully understood at present Despite excellent early results reported by some there is some evidence of poor later results[17]

Late patency studies of autogenous venous grafts indicate that

if such a graft remains patent through the period of hospitalization, there is a great likelihood that it will do so for a considerable period of time since it continues as a viable tissue Table VI on page 36 summarized available information on this point

Degeneration

Degeneration occurs in homologous arterial grafts as discussed above, and also in terms of atherosclerotic deposition of lipids under and in the neo intima of synthetics Increasing evidence indicates over all unsuitability of the homologous artery because of this The development of atherosclerotic plaques within the pseudo intima lining synthetic tubes has been noted in animals followed for long periods by DeBakey[3] The synthetic tube does not degenerate in the sense that tissue does, but it has been suggested that certain plastics lose tensile strength after a period of time implanted in the tissues Nylon is reported to be particularly weak after a period of time[9]

Autogenous venous grafts persist as a viable tissue and have shown no tendency to undergo degeneration Fears that a high rate of aneurysm formation would occur are not justified This fear was based upon the occurrence of aneurysms in large veins transplanted into the aortas of animals (particularly pigs) and did not arise from any particular instance of aneurysm formation in small peripheral venous transplants Reference to Table VI on page 36 will indicate that only two references to aneurysm formation in a clinical peripheral venous replacement were found Previous confusion between homologous and heterologous venous transplants (which do degenerate and form aneurysms) and with autogenous venous transplants which remain viable and do not form aneurysms should cease There has been no reported instance of atherosclerotic plaque within an autogenous venous transplant

Viability

Synthetic tubes are, of course, non viable materials and cause a foreign body reaction even though with certain ones this may be minimal The homologous artery also constitutes a foreign body and is gradually infiltrated with fibrous tissue while its elements

slowly degenerate the elastic fibers persisting for long periods of time before their final dissolution Since the homologous artery actually functions only as a splint and since certain synthetics have other advantages over arterial homografts the latter are preferred Experimental as well as clinical evidence indicates long term viability of autogenous veins

Resistance to Infection

Both homologous arteries and synthetic tubes are essentially foreign bodies and as such incite a reaction and encourage infection to some extent Infection is particularly likely to result in arterial homograft blowout from proteolytic enzymatic necrosis of the wall The same does not occur with a synthetic tube although the suture line may disrupt [16] Harrison [8] studied the differences in dogs between Teflon and homografts placed into the aorta in the presence of infection and concluded the synthetic tube to be more desirable The reaction of the autogenous vein (on the basis of clinical experience) appears to be thrombosis rather than blowout. Furthermore since this is a viable tissue prompt and thorough drainage of infected regions may permit patency of the autogenous vein to continue since infection will not necessarily continue

Graft Bleeding

Neither the homologous artery nor the autogenous vein causes any particular bleeding problem after the anastomoses are made and clamps removed Small leaks at the suture line are ordinarily easily controlled with pressure from 3 to 5 minutes An occasional reinforcing suture may be necessary to stop a gap in the suture line from bleeding There has to date been considerable variation in the amount of bleeding through synthetic tubes and this appears to be related to porosity of the tube and lack of quality control of this during manufacture

Despite pre-clotting measures occasional major difficulty has occurred with continued bleeding through the graft in the hands of the author as well as colleagues with the use of several types of synthetic tubes In a series of 32 synthetic tube replacements of the canine thoracic aorta (while circulation was maintained by me

chanical pump from either left atrium or left subclavian artery to distal aorta in dogs) there was a high instance of continued bleeding to final cardiac arrest or ventricular fibrillation despite protamine reversal of heparinization used during pump shunting The grafts were pre clotted This bleeding phenomenon is not understood and requires further investigation but may be similar to that which has been observed in a few human cases using synthetic grafts The possibility of some effect of the synthetic material upon the clotting mechanism (possibly by virtue of the electrical charge) has been considered and requires investigation

Antigenicity

Lord and Lazzarini [14] have suggested that occasional immunologic responses may occur after homografting and the author has had one late postoperative death (49th day of hemolytic anemia) after aortic homograft replacement which appeared due to this Such are unknown after either vein or synthetic transplants

Pulse and Flow Transmission

Experimental studies cited in Chapter II indicate that there is little to choose between homologous arterial autogenous venous and synthetic tube grafts so far as proper transmission of pulse pressure and blood flow are concerned

Accumulated Experience

Accumulated experience with homologous arteries is considerably more because these were first used as grafting materials Their early promise has not been borne out and their present use is in general quite limited A large number of various synthetic tubes have been placed in various centers to date Their early results are likewise excellent but late results not well reported While no large number of autogenous veins has been placed reports of these (summarized in Table VI on page 36) date back a good many years and indicate that if early patency is obtained late patency is apt to follow Particularly in non atherosclerotic cases have the results of autogenous vein grafting been excellent when followed for long periods This appears to indicate that poor results in peripheral

occlusive disease may be primarily due to the disease process itself and not to the autogenous vein graft On the other hand large numbers of long autogenous vein grafts have not yet been done and further study of these is necessary

Individual Experience

In Table VII this is indicated by question marks under each type graft because each surgeon s general as well as vascular background is different It is to be hoped that the type of direct surgical treatment will be fitted to the individual case It is recognized that unless a particular material and the technic of its use will produce good results for numbers of surgeons that the method will not acquire widespread usefulness The history of certain unrelated operations bears this out in that a considerable time was necessary for evaluation of the claims of the early enthusiastic proponents against the somewhat later doubters until sufficient numbers of surgeons had obtained proper background to evaluate results accurately The same will doubtless be true not only of the various available operations for peripheral vascular insufficiency but also of the available materials for peripheral shunt grafting

In summary it may be said that *homologous arteries* are not always available and constitute a difficult handling problem as well as resulting in a fairly high proportion of late degeneration and graft failure The ready availability of *synthetic tubes* is their greatest advantage but bleeding at operation and susceptibility to infection constitute bad points While reported early results are good the later results are poorly understood and there is increasing evidence of late failures The more difficult technic of autogenous *vein* grafts appears balanced by their viability within host tissue and by their continued patency once in place

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Chapter VII

OPERATIVE TECHNIC

The general operative management of an autogenous venous shunt graft is of course similar to that for placing grafts of other materials into the peripheral arterial system Certain necessary modifications are due to the inherent friability and wall thinness as well as the valves of veins Overall *attention to delicacy of technic* both in removal and placement of the graft appears of particular importance As Bernheim pointed out in 1913 the success of blood vessel work anastomoses repair of injuries etc depends almost entirely on the avoidance of blood clot [1] Widely patent stomas at sites of anastomosis are also mandatory

Every effort should be made to avoid pinching or otherwise traumatizing the vascular walls It should be recognized that the tissue can usually be managed by pushing it gently in one direction or another without the necessity actually to squeeze the tissue to pick it up During the course of anastomosing the vein to the artery when very fine suture bites are necessary it is well to operate in a sitting position with the forearms resting firmly on the operating table Self retaining retractors usually expose the tissues in a more constant fashion than do multiple hand held retractors although the latter are necessary in one or two positions (1) retracting the vastus medialis during popliteal anastomosis and (2) retracting the inguinal ligament during common femoral anastomosis

Position of the Patient

The necessary position on the operating table is dependent upon whether the distal anastomosis can be performed proximal to the knee joint or whether it will be necessary to split the calf muscle and join the graft to the distal popliteal artery or proximal part of the posterior tibial artery distal to the knee joint Anastomosis proximal to the knee joint can be satisfactorily performed through a medial low thigh incision retracting the sartorius muscle medially and posteriorly Thus it is only necessary for the patient to lie

supine on his back with the lower extremity externally rotated to allow sufficient exposure at both the femoral and popliteal areas (top of Figure 18)

If it is likely that exposure below the knee joint will be necessary, the patient should be in a position whereby one can gain entry to the distal popliteal artery and proximal portion of the posterior tibial artery by splitting the calf muscles After trial with several positions, the most satisfactory one for a very distal anastomosis appears to be a moveable position whereby the patient initially lies on the involved side with both lower extremities surgically prepared and draped For the femoral portion of the dissection, the contralateral uninvolved extremity is moved posteriorly so that the patient rolls partially backward and allows easy access to the femoral region For the distal popliteal exposure, the uninvolved contralateral extremity is moved forward and placed anterior to the involved lower extremity so that posterior access is gained to

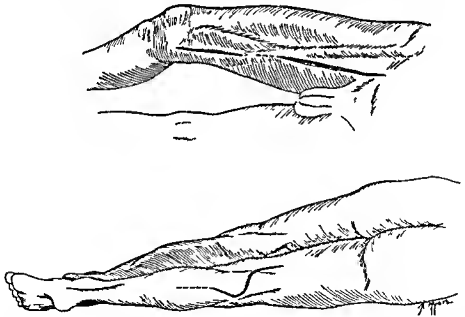

Fig 18 Incisions At *top* are femoral and distal medial thigh incisions used for femoral shunt grafting Broken line shows alternate single long incision *Bottom* shows contralateral leg swung over anterior to operative side to allow posterior approach to popliteal space S incision gives access to distal popliteal and posterior tibial arteries

the popliteal space and calf with the patient rolled over into the slightly prone position (bottom of Figure 18) This allows a wider exposure through a long S-shaped incision across the popliteal space than does the medial calf incision [24]

In the event that there is any doubt that the patient may require anastomosis distal to the knee joint, the second moveable position should be used from the start since more flexibility is permitted with this than if the patient simply lies supine on his back A simple supine position should be reserved for patients with arteriographic proof of good distal run-off circulation bearing in mind that the artery is always more diseased than indicated by the x ray

Draping

Any convenient form of sterile draping may be used whereby easy access is gained to both the proximal femoral region and the distal popliteal region It should be borne in mind that frequently the proximal incision must be carried up across the inguinal region to permit retraction or cutting of the inguinal ligament in order that a proper common femoral or external iliac anastomosis can be performed

The distal draping can be done in several ways but the use of double orthopedic stockinette has several advantages First this stockinette furnishes a smoothly fitting easy applied draping for both lower extremities so that any position may be used Second a scissors opening can be made at any point in the stockinette with ease Third if the stockinette is turned under and the smooth folded edge is sutured to the skin margins under a moderate degree of tension the elasticity of the stockinette helps considerably in retracting the wound edges during the procedure The contralateral uninvolved extremity should be similarly draped in the event there is a slightest possibility that it will need to be swung over to allow a distal popliteal anastomosis to be made

Incisions and Dissection

Initially autogenous venous grafts were removed and placed through a femoral incision and a separate popliteal incision tunnel ing in between After a number had been done this way it appeared

that the uncut skin of the central portion of the thigh often developed an undue amount of edema and induration postoperatively and that this was due to difficult and vigorous retraction to permit the removal of the graft and tunneling. Recently, therefore, a single long incision has at times been used (broken line in top of Figure 18). This has the advantage of permitting easy visualization of the entire length of the graft and accurate hemostasis both of the graft and of the tissues of the patient.

The incision is begun over the femoral region and the saphenous vein located as the first step in order to prevent inadvertent injury to the autogenous venous graft (Figure 19). As soon as the proximal portion of the saphenous vein has been located, it is followed distally for a convenient length (of 4 to 5 inches) in order that the entire femoral skin incision may be opened up to permit dissection of the femoral arterial vessels before proceeding more distally.

Proximal Femoral Dissection

With the saphenous vein accurately located and protected from harm, the proximal femoral arterial dissection is carried out and

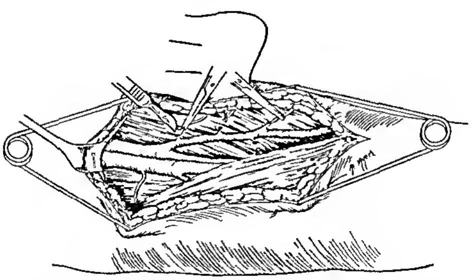

Fig. 19. Femoral dissection. Dotted line shows site for anastomosis to common femoral artery. Tributaries of saphenous vein are being cut after ligation on vein side and clamping peripherally.

Penrose drains passed about the common femoral deep femoral and superficial femoral arteries Sufficient dissection is made to be certain that the anastomosis to the common femoral artery can be carried out later without the necessity for further dissection

Removal of Vein Graft

Following completion of proximal femoral arterial dissection attention is turned to the removal of the saphenous vein graft In cision is continued distally over the course of the saphenous vein and all tissue anterior and medial to the vein is cleared by sharp dissection so that the surface of the vein is completely exposed A Penrose drain is then passed about the vein and it is elevated care fully as each tributary is in turn ligated with fine silk on the vein side and clamped on the tissue side prior to cutting the tributary Dissection proceeds distally handling the vein by the encircling Penrose drain and never picking it up with a pinching or grasping instrument Clamps are left on the tributaries temporarily in order that the vein may be removed and irrigated as rapidly as possible The vein dissection is carried distal to the knee joint by retracting the lower aspect of the incision to insure that a sufficient length be obtained for the vein graft In the lower part of the incision the saphenous vein is often bifid and one should look for this large tributary and follow the largest portion of the vein for the part to be used as the graft

A marking suture of fine arterial silk is placed through the venous wall as proximally and as distally as possible prior to re moving the vein in order to mark the longitudinal position of the vein and prevent later twisting when the graft is placed These suture ends are left long for easy identification Clamps are then placed proximally and distally and the vein graft removed. Im mediately a small polyethylene cannula is passed into the distal end of the vein graft and heparinized saline (50 mg Heparin per 200 cc of saline) is used to irrigate the interior of the vein graft to remove all blood and prevent deposition of clot (Figure 20) The vein graft is then dropped into the heparinized saline basin Ties are placed on the tributary clamps and accurate hemostasis checked throughout the wound

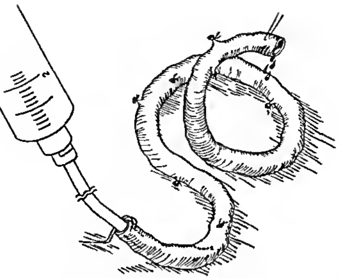

Fig. 20 Irrigation of vein graft Heparinized saline is flushed from *distal to proximal* end of excised vein graft at once All tributaries have been tied prior to final excision Long sutures at ends orient long axis of graft

Distal Popliteal Dissection

Attention is now turned to the distal dissection of the popliteal artery The popliteal artery proximal to the knee joint is reached by retracting the sartorius muscle posteriorly and medially and elevating the vastus medialis anteriorly (Figure 21) Ordinarily the thickened arterial wall is palpable with the finger in the fat of the popliteal space Extreme care in its dissection will prevent injury to the popliteal vein which can be not only the source of bleeding during the operation but also the cause of later venous thrombosis The popliteal artery is handled by encircling it with a Penrose drain as quickly as possible Efforts are made to preserve all arteries leaving the popliteal artery but occasionally one geniculate artery will require sacrifice for proper exposure or for proper anastomosis

The tendinous portion of the adductor magnus muscle through which the superficial femoral artery courses to form the popliteal artery can be palpated by passing the finger up along the proximal reaches of the popliteal artery This should be elevated over an instrument and cut down to the femur to decompress widely the

hiatus in the adductor magnus It does not require resuture at completion of the operation since this forms only a small portion of the entire insertion of the adductor magnus muscle Frequently one or two bleeding points require ligation following this dissection

In the event that more distal anastomosis proves necessary the patient is rolled into the partially prone position to allow entry through the middle of the calf (bottom of Figure 18) Incision across the popliteal space should be in the form of a lazy S to avoid contracture across this flexion crease The proximal length of this incision is placed on the medial aspect of the thigh and the distal end courses down the lateral aspect of the lower leg and bends back toward the mid line Small rounded skin and fat flaps are dissected off the fascia and this opened over the gastrocnemius muscle beside the medial sural cutaneous nerve and the lesser saphenous vein lying together in the mid line The muscle belly is split in the mid

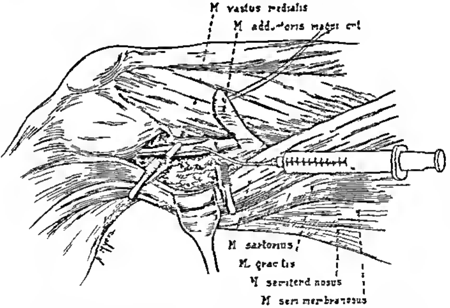

Fig 21 Popliteal dissection Sartorius and vastus medialis muscles are separated to allow access to popliteal artery Ten cubic centimeters of heparinized saline is being injected distally via arteriotomy prior to anastomosis. The distal tendinous portion of the adductor magnus muscle has been cut away from the femur and retracted by stay suture

line to allow access to the distal popliteal artery and proximal posterior tibial artery In this instance also care is necessary to prevent injury to the accompanying veins A definite search should be made for the laterally coursing anterior tibial artery which comes off almost at a right angle Anastomosis proximal to this can be accomplished somewhat more easily than distal because the popliteal artery is larger than the posterior tibial artery but the latter anastomosis has been satisfactorily performed in several instances

At times after a medial low thigh incision has been made it has been found that the popliteal artery is not sufficiently patent in its upper reaches to allow anastomosis with a good chance of success In that event the patient should be rolled and incision made through the calf muscle to permit a lower anastomosis If the proximal popliteal artery has already been opened it is repaired by continuous over and over arterial suture

Proof of Distal Vascular Patency

The preoperative arteriogram should be compared to the operative findings carefully to ascertain the optimal level for the distal anastomosis Temporary removal of the distal popliteal clamp should allow free back bleeding if the distal vessel is patent In addition a polyethylene cannula of proper size should be passed distally through an arteriotomy (Figure 21) in order to ascertain that there is no block as well as to allow injection of heparinized saline (50 mg per 200 cc) in 10 cc amounts every 30 minutes while the vessel is clamped This as well as minimal time of occlusion of the circulation serves to prevent small vessel thrombosis distally Usually only a single injection is needed Should the polyethylene cannula demonstrate a distal partial block the anastomosis should be made further down to avoid the distinct hazard of thrombosis when done proximal to such partial occlusion

Handling the Graft

The venous graft should be handled with an encircling Penrose drain and not with grasping or pinching forceps during its dissection Following its removal the ends of the graft may be handled with steel instruments provided they are later cut away Ordinarily

about 5 millimeters of each end of the graft is cut away to remove not only the marking suture placed to orient the graft but also to remove portions handled by the small tweezers during the early stages of anastomosis The vein graft should not be allowed to dry out while anastomosis is being performed, and one assistant should be detailed to keep this moist with heparinized saline

Suture Material

Five-0 silk on small 3/8 round needles is the material of choice because of its strength and ease of handling Finer material (6-0 silk) can be used but does not furnish a sufficiently large reserve of strength for ordinary use and is too likely to be broken inadvertently at the time of tying a knot It is not much finer than 5 0 silk and does not appear to offer a very great advantage in terms of size but has the disadvantage of increased weakness during tying Since the widely used mineral oil causes greasy fingers and slippage of instruments, it is preferable to lubricate lightly the suture material either with saline or by passing it through the patient s own adipose tissue

Instruments

Delicate iris tweezers are used to handle the venous graft and the arterial wall in order that a minimum of pressure will be used Excessive pressure upon these tiny tweezers results in the two blades passing across each other and therefore losing hold upon the tissue A small pair of Metzenbaum scissors is useful for trimming adventitia off the artery and for trimming the ends of the vein Angled Potts scissors are used to enlarge the knife opening in the artery Any of several forms of delicate needle holders are useful for handling the suture material Several sizes of polyethylene tubing should be available not only to use to irrigate the interior of the graft but also so that a small piece can be used as an internal stent during portions of anastomosis If thrombectomy is necessary anytime during the procedure these insure properly fitting sizes of tubing to pass in either direction in the artery or in the vein Sizes PE 205, 280, 330, 360 and 390 have proved useful (Figure 26 on page 96)

Vascular clamps with teeth should be avoided since later examination of vessels held by these often shows intimal scarring Serre fine bulldog clamps are preferable Lightly cross hatched serrations of their opposing jaw surfaces help hold the vessel securely There is no need to cover the jaws with rubber as is commonly done

Anastomoses

The anastomotic opening should be large in relation to the lumen of the vessels to allow for inadvertent constriction as well as for later scarring A ratio of 3 to 1 between stoma and arterial lumen is recommended It is not ordinarily necessary to cut away any portion of the arterial walls since the pressure of blood flowing through will hold this open unless there is a great degree of stiffening of the artery due to atherosclerosis

The vein is grasped at its originally proximal end as the popliteal anastomosis is begun (in order that the vein graft may be reversed and the valves lie in the proper direction) While the originally proximal end of the vein graft is held the scissors are used to split one side for a distance a little longer than needed to fit against the already opened artery (Figure 22) A mattress suture is now placed between the proximal end of the opening in the vein and in the artery placing the tie on the arterial side and drawing this down snugly A similar mattress suture is placed at the other end of the anastomosis and just before tying this down the tip of the vein is cut away along with the marking stay suture in the traumatized end of the vein (These two stay sutures insure that the relation of the length of the opening in the vein to that of the artery is proper) The sides of the spatulate opening in the end of the vein are now trimmed away with scissors

Initially the mattress suture lying at the distal part of the popliteal anastomosis is carried as a continuous over and over suture proximally taking tiny bites and essentially joining the artery and vein edge to-edge without attempting to evert the tissue The mattress suture at the ends of the anastomosis help to evert slightly the venous and arterial walls so that very little suture material lies bare within the lumen (Figure 23)

When this suture line reaches the other stay suture the two

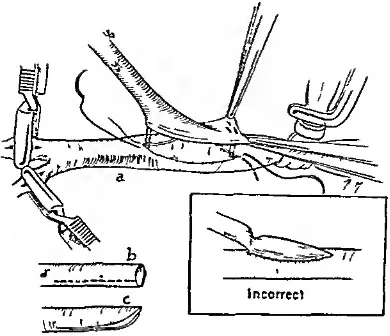

Fig 22 Anastomosis details. (a) Mattress sutures between vein graft and femoral artery (b) Vein opened down one side and (c) tips cut away *Inset* shows constriction produced by incorrect suturing

are tied together The long end of the proximal stay suture is now used to place a continuous over-and-over line distally and is tied to the other stay suture While the suture is being placed to the proximal portion of the anastomosis it is helpful to place the largest size polyethylene tube which will fit into the vein to insure that no constriction occurs there by virtue of suturing (inset of Figure 22) This is removed before completion of the second side of the anastomosis (Figure 23)

The vein is now drawn out full length and oriented by means of the other stay suture to insure that twisting does not occur *It is* pulled within a small Penrose drain and held there with a suture or tie while the drain is tunneled (through the enlarged opening in the adductor magnus muscle) under the muscle up to the femoral region The Penrose drain is pulled through leading the vein along with this and the drain removed from the end of the vein

After the common femoral artery is opened and the originally distal end of the saphenous vein split to match this, mattress sutures

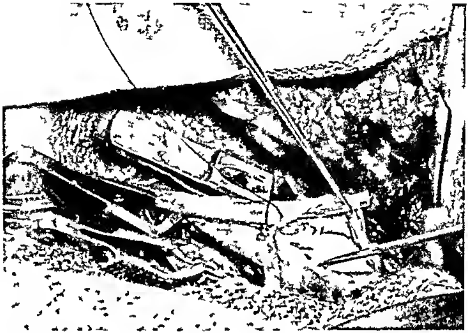

Fig 28 Half completed anastomosis of vein to femoral artery viewed from intimal aspect Polyethylene stent lies about an inch within vein graft to insure against constriction by suturing It is removed just before completion of the suture line

are placed to start the anastomosis and then carried as continuous over and over sutures to complete the femoral anastomosis

Distal clamps are removed initially followed at once by the proximal clamps and dry sponges held over the anastomoses for 3 to 5 minutes to allow bleeding through needle holes to cease Occasionally patch sutures will be necessary to control bleeding but great care should be taken that these do not constrict the lumen of the vein Most such anastomoses will be water tight and only an occasional extra stitch will be necessary

In an occasional instance strands of adventitia may compromise the lumen of the vein graft either at the stoma or somewhere in its course and it should be carefully inspected for these prior to closure

Drains

Doubled quarter inch Penrose drains should be led out from both the femoral and popliteal regions to insure that if bleeding

Fig 94 Completed anastomoses between autogenous saphenous vein and (a) common femoral artery and (b) popliteal artery

occurs into the wound, it will not form a clot and tamponade the graft and result in thrombosis and also to warn the surgeon should bleeding occur For this reason, only a light dressing is placed and the nurse is instructed to notify the responsible physician should any undue amount of drainage appear through this light dressing

Dressing

Light dressings are used and encircling constriction is avoided

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Chapter VIII

PRE- AND POSTOPERATIVE CARE

PREOPERATIVE MANAGEMENT

PRIOR TO OPERATION patients require the same general care as for any major operation Besides the usual measures designed to screen the important functional systems of the body such as the heart lungs alimentary canal liver and kidneys certain other points are worthy of brief discussion

While it is often possible to make arteriograms at the time of operative exposure for definitive surgery (rather than in the pre operative period) it is desirable to have these x rays available for consideration and discussion well ahead of operation rather than to make a relatively rapid decision on the basis of an operative arteriogram with the patient anesthetized in the operating room In the occasional patient with high superficial femoral occlusion it may be difficult or impossible to place the needle into the femoral artery to obtain this information prior to operation In such instances it is usually preferable to expose the popliteal artery at operation for the primary purpose of performing an arteriogram and at once follow this with direct arterial surgery if the distal vessels are suitable Also if there is a doubt regarding the suitability of the distal run-off circulation after preoperative arteriograms have been done graft placement should be preceeded by a direct operative popliteal arteriogram to ascertain that such surgery is actually worthwhile

One of the advantages of autogenous venous shunt grafting is the relative bloodlessness (as compared to porous synthetic tubes) of the procedure so that blood transfusions are not required while the patient is anesthetized If preoperative study indicates anemia and the need for transfusion it is safer for the patient to have this preoperatively in a conscious state rather than later under anesthesia because of easier and more certain recognition of transfusion reactions Because adequate blood flow through the graft is important to continued maintenance of patency through the early healing

period, any defect in blood volume should be replaced prior to surgery

Because of the common association of atherosclerotic occlusion of the femoral popliteal system with similar lesions elsewhere, it is important to obtain not only a careful history of the cardiac situation, but also an electrocardiogram, not only to detect possible early changes but also to serve as a baseline in the event that some change in the clinical condition during operation or in the postoperative period makes necessary an electrocardiogram to determine whether or not an acute cardiac episode has occurred Furthermore, certain patients with particularly severe coronary arterial disease are probably better left with peripheral arterial insufficiency resulting in calf claudication to act as a brake upon their activity and to prevent exercise harmful to the heart

The presence of tissue necrosis of the distal portion of the lower extremity is no contraindication to graft placement In the occasional patient with toe gangrene indicating that some form of amputation will be necessary, the wound can be expected to heal considerably better if an increased blood supply be directed to the foot While there may be doubt that pre amputation sympathectomy influences healing of the amputation wound, it is apparent that major portions of some extremities have been saved by the return of blood flow via a graft followed by relatively minor distal amputation Judicious use of antibiotics and protection of dry gangrene from moisture (or opening up areas of moist gangrene with debridement) may be important adjuvant measures prior to and during the immediate postoperative period after shunt graft surgery

Postoperative Care

Most of the principles of postoperative management following placement of a peripheral shunt do not differ from those following any major operation or anesthesia Attention is therefore chiefly directed toward particular features which may require some variation from standard management.

Relief of Pain

Despite the considerable deep dissection often necessary during the placement of a peripheral graft, the wounds often are not very

painful because they are well splinted by the underlying femur and often do not cross flexion creases Reasonable amounts of medication will usually suffice to control postoperative pain One of the chief advantages of the use of continuous epidural anesthesia for the operation is the availability of pain control by further injection of aliquots of anesthetic solution into the epidural space at intervals during the postoperative period These injections during the first 48 postoperative hours not only control pain but also result in block of vaso-constrictor fibers concurrently The small indwelling polyethylene catheter can be easily removed from the back at the end of that period

Ambulation

Relatively early walking is encouraged following vascular grafting of all sorts If the graft crosses a flexion crease either at the popliteal region or the femoral region the patient is requested not to flex the extremity to an acute angle beyond 90° and a few patients thought to be generally uncooperative are placed into a brace extending from the shoe up across the knee with a locking device at the knee to prevent flexion beyond 90° or have a posterior leg splint placed This is unnecessary for most individuals Sitting is discouraged to prevent pressure of the edge of a chair or bed on the distal graft or anastomosis and also because it tends to increase any edema which may develop distally as discussed below

Dressings

A soft Penrose drain is led out of each wound taking care to suture this to the skin edges so that it projects into the depths of the wound but does not touch the artery or the anastomosis This is placed to allow ready escape of serum or blood which may accumulate and thus prevent tamponade of the graft. It may also serve to warn the attendants should partial disruption of the anastomotic suture line occur and require repair These drains are removed at the end of 36 to 48 hours The mattress sutures placed on either side through the skin edges then automatically pull the skin together and result in complete sealing of the wound

Skin sutures of the lower extremity are left in somewhat longer

than elsewhere Since suture material causes a foreign body reaction, it is often appropriate to remove about half the sutures at 5 to 7 days following operation and leave the remainder until the wound is better healed at 10 to 14 postoperative days Below the knee where healing is apt to be particularly slow, #40 stainless steel wire is preferred to either silk or cotton skin suture material because it results in considerably less inflammatory reaction in the skin and may therefore be left in place for a longer period

Light dressings are placed immediately after operation and each time the wound is dressed in such a way that the extremity is not encircled by either bandage materials or adhesive tape to prevent constriction should edema occur Should the graft cross the popliteal flexion crease and extend into the calf, a posterior hamstring splint may be padded and applied to the posterior aspect of the extremity to prevent knee flexion during the early postoperative period This is attached to the extremity by adhesive strips which do not completely encircle it Although a bit awkward the patient is able to get out of bed and walk fairly well with such a splint in place for approximately 10 days

Groin wounds are particularly prone to maceration because of sweating and overlying occlusive dressings, and in the event that this begins to occur there should be no hesitation in completely removing the dressings in that area for exposure to air to allow drying of the area

Antibiotics

Because of the extensive area ready access of bacteria to the blood stream and great importance of prevention of infection, a broad spectrum antibiotic is administered for the first 5 to 7 post operative days (One hundred milligrams tetracycline intramuscularly is given immediately after operation and three times daily until the patient is ready to tolerate 500 milligrams by mouth four times daily)

Blood Loss

Because of the sometimes inadvertent loss of more blood than is recognized at operation some check should be made on the fol

lowing day, usually in the form of a hematocrit determination. Since hypovolemia is thought to predispose to a decreased blood flow and likelihood of thrombosis, a postoperative transfusion is given should it be indicated.

Pulse Checks

Immediately following operation, a chart (Figure 25) is begun to indicate what peripheral pulses are palpable and what the oscillometer shows Each hour, a responsible attendant (who may be a nurse, house officer, or surgeon) should examine the dorsalis pedis and posterior tibial pulses and record their presence or absence along with the oscillometric reading and initial the chart. So long as the pulses remain steady or become increased in amplitude, this routine is continued. Should either pulse disappear or the oscillometric reading greatly decrease, it is mandatory that a responsible attendant be immediately notified to make a decision as to whether the graft has thrombosed and requires immediate exploration. In two instances to date, it has been possible to clean out such early thrombosis and salvage patency of the graft by immediately return-

Post-operative Pulse Check

Name: J. Brown　　　Number 23105

Date	Hour	Pulses PT	Pulses DP	Oscillometer at calf	Initial
3/4	2PM	+	+	1/100	WDB
	3PM	+	+	1½/105	EC
	4PM	+	+	1¼/95	WDB

Fig 25 Chart to show postoperative pulse checks following shunt grafting to emphasize attention to function of the graft during the immediate postoperative period

ing the patient to the operating room for exploration and thrombectomy Such thrombosis becomes firmly attached to the vascular wall within a relatively short time and immediate action is essential (as in arterial embolectomy) Pulse checks are therefore continued day and night for 3 to 5 postoperative days

Illustrative Case

A 65 year-old white male with intermittent claudication in the right leg had no pulse distal to the femoral artery There was a palpable left popliteal pulse Right femoral arteriogram showed a superficial femoral block with good distal reconstitution An autogenous venous shunt graft was placed from the common femoral to the popliteal artery This functioned well for a brief period and then was suddenly found to be completely thrombosed A venotomy was therefore made 5 cm distal to the proximal anastomosis and a properly fitted polyethylene tube passed through the vein graft in both directions This removed soft thrombus The tube was removed and the opening in the vein sutured with *continuous 5 0 silk Postoperatively there was* excellent pulsation

Comment Immediate recognition of and treatment to the acute thrombosis allowed complete removal of clot and ultimate excellent results in the graft Figure 26 shows the doubly packaged 30 in polyethylene tubes* kept (gas) sterilized in constant readiness for such use

Postoperative Arteriograms

Postoperative arteriographic examination at proper intervals is *important as a check upon the condition of the extremity* and the graft and to enable proper instructions to the patient In general an attempt is made to perform the first postoperative arteriogram as soon as complete healing of all wounds has occurred but only if it is possible to place the arteriographic needle proximal to the anastomosis of vein to artery This initial arteriogram should establish graft patency and also serves to warn of constriction or twisting at any point Following this it is desirable to obtain a postoperative arteriogram at yearly intervals or sooner if symptoms

*Obtainable from the Klista Co 712 39th Ave N Nashville Tenn

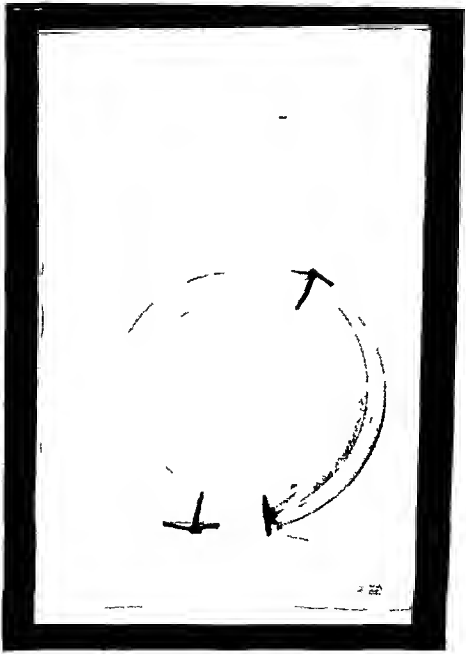

Fig 96 Thirty inch long sterile polyethylene tubing for use as endo-arterial suction cannula This is contained within a double polyethylene-cellophane container and has been gas sterilized so that it is ready for use immediately Five sizes are available

indicate such need in order to advise the patient properly during the later postoperative period

Illustrative Case

A 77 year-old white male had a history of left calf claudication limiting walking to a block for about four months with increase for the last 5 or 6 weeks Priscoline had been without effect There was a palpable popliteal artery and dorsalis pedis artery on the right but no pulses distal to the femoral on the left A left femoral arteriogram (Figure 27a) showed a 7 cm block at the distal superficial femoral artery with good popliteal reconstitution but with block at the bifurcation so that the only direct blood flow was by the anterior tibial which also showed some scalloping as evidence of atherosclerosis

An autogenous venous shunt graft was placed from the superficial femoral artery just distal to the common femoral arterial bifurcation to the popliteal and the dorsalis pedis pulse became palpable the same day On the 12th postoperative day the left femoral arteriogram showed a widely patent vein graft (Figure 27b)

Postoperatively claudication was completely relieved Swelling of the ankle and foot was controlled by elastic bandaging Five months postoperatively the patient was complaining of very slight claudication in the lateral aspect of the lower leg and upon examination the dorsalis pedis pulse had disappeared and the oscillometric index in the calf had decreased from 3 to ½ The graft pulsation was palpable in the popliteal space Six months after operation a left femoral arteriogram (Figure 27c) showed the graft to be widely patent There had been progression of disease which had occluded the distal portion of the popliteal artery and completely blocked off the anterior tibial artery Circulation to the distal part of the lower extremity was *now carried by tortuous collaterals below the knee*

Comment The vein graft was still patent but progression of the basic atherosclerotic disease was clearly indicated by the arteriogram

Miscellaneous

The patient is given a steadily increasing diet as tolerated is encouraged to breathe deeply cough and turn every two hours day

Fig 27 Progression of underlying atherosclerosis despite successful shunt grafting (a) Relatively short atherosclerotic occlusion at adductus magnus hiatus with proximal scalloping and irregularity, and distal similar changes and complete absence of posterior tibial artery at lower arrow (b) The patent autogenous venous shunt graft 11 days after operation (c) The patent shunt graft six months after operation with occlusion of the distal popliteal artery at the arrow indicating progression of disease since the "b" arteriogram This was associated with anterolateral lower leg claudication as the anterior tibial artery became occluded.

and night for the first 72 hours and thereafter as indicated and otherwise receives management consistent with his general situation.

Chapter IX

COMPLICATIONS

BLEEDING

While it is possible that excessive bleeding along the drains left in place in the wounds is due to an untied vessel in the wound itself attention should be immediately directed toward the possibility that the bleeding is arterial in origin from the anastomotic site or (as occurred in one case) from a point in the graft itself Early re exploration is therefore in order This may show that because of clotting within the wound some degree of tamponade has occurred and resulted in graft thrombosis Such is managed as discussed be low at the same time that the bleeding point is controlled *Post graft bleeding should not be managed conservatively* Immediate intervention is indicated to control hemorrhage and salvage the graft

It is difficult to lay down hard and fast rules regarding methods for cleaning out the graft In general if a satisfactory suture line has been made at the original anastomosis it is probably better to leave this alone and to explore and remove clot either through an opening in the artery or the vein by passage of polyethylene cathe ters through the anastomosis Both methods have been successful in our experience A series of graded sizes of polyethylene catheters 30 in long (Figure 26 on page 96) are maintained (gas sterilized in double bags) at all times so that the properly fitting one can be passed either through an arteriotomy or a venotomy to remove thrombus either in a graft or after embolectomy Such a polyethy lene catheter is slowly advanced while suction is maintained on a 30 cc or 50 cc syringe attached to the other end Progressively larger or smaller sizes are used as the tube is passed either proximally or distally as indicated A pulsatile flow of blood should be obtained proximally and a free non pulsatile flow obtained distally before one is satisfied that the vessel has been properly cleaned Experience using this method has to date been better than irrigating via the posterior tibial artery exposed at the ankle [1] although that has been used occasionally

Sometimes, secondary or tertiary thrombosis recurs after a graft has been cleaned out. In this event, general heparinization may permit the graft to remain open where it could not be salvaged without this.* Experience in this series and in other vascular surgery where systemic heparin was used at the time of operation has been bad in that even though this was administered initially after the lapse of some hours, there has been bleeding into the wound and sometimes this has resulted in skin flap necrosis and/or infection.[4] Heparinization of a patient with the extensive wounds used for this form of grafting is to be avoided except as a last resort measure. In the event that it appears mandatory, proper drainage is suggested.

Progression of Disease

Since grafting is a palliative operation for a slowly progressive lesion, it may be expected that further changes will occur after operation. Shunting from the common femoral completely down to the popliteal artery is designed to by-pass that portion of the superficial femoral artery which is most frequently the site of thrombosis once atherosclerotic lesions begin and has a considerably better outlook that did short by-passing grafts which often become occluded because of immediate disease progression. An example of distal progression of disease beyond a patent graft is seen in Figure 27 on page 98.

An example of the fairly common immediate progression of the thrombosis that often occurs in the superficial femoral artery after the placement of a shunt graft is seen in Figure 28 which shows the preoperative arteriogram as well as a repetitive study 22 days after operation. There is little doubt that shunting led to further thrombosis of the distal superficial femoral artery. That is not unexpected nor is it dangerous so long as the graft remains patent. Should the graft fail however, the distal extremity may be seriously compromized since the excellent blood flow through the graft removes the stimulus to collateral formation. Proponents of thromboendarterectomy believe that failure of a thromboendarterectomized ar-

*Although is was originally hoped that regional heparinization would prove valuable in this situation, it has been shown that such is temporary and proceeds rather quickly to a generalized heparinization[a] and the latter is therefore used.

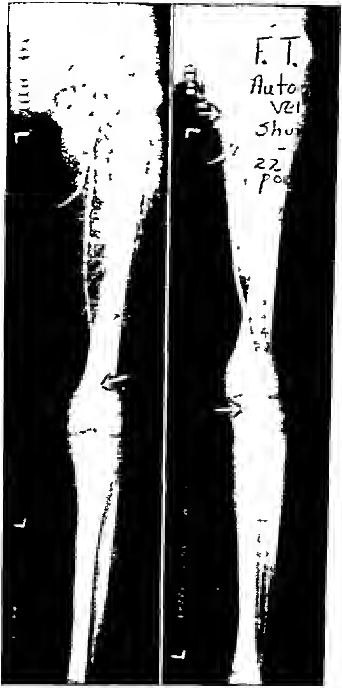

Fig 28 Progression of thrombosis of femoral artery after grafting (a) Complete occlusion at arrow as well as proximal popliteal artery with proximal scalloping and irregularity (b) Patent autogenous venous graft 22 days after operation with complete occlusion of most of the distal portion of the superficial femoral artery

tery is less likely to be acute and therefore less apt to result in amputation directly due to failure of the operation. Analysis of experience with amputations necessary in the immediate post graft period has indicated that no extremity has been lost to date primarily because of failure of the shunt graft,[7] although in two instances the threatened loss was hastened.

Venous Thrombosis

Edema of the distal lower extremity following peripheral grafting is an occasional occurrence. This does not ordinarily progress to a painful calf or positive Homan's sign (unless the calf muscles have been split for a distal anastomosis which produces calf tenderness). For a time it seemed possible that the edema might be due to the increased flow of blood into an arterial and capillary system which had long been unaccustomed to such. One case ruled against that hypothesis.

Illustrative Case

A 56 year-old male who had bilateral calf claudication had a long femoral block on the right and a very short one on the left (Figure 29 on page 101).

An autogenous venous shunt graft was placed on the right without difficulty. Directly thereafter a left open thromboendarterectomy was done. All pulses were at once apparent.

Pedal and ankle edema occurred in the early postoperative period on the right side (where vein grafting had been done) but not on the left. An elastic stocking was used to control this.

Comment: More operative trauma to the vein undoubtedly occurred at shunt grafting on the right than at short thromboendarterectomy on the left and resulted in venous thrombosis. Excellent return of circulation to both feet with bounding pulses ruled against change in arterial flow as the cause of unilateral edema since it had been greatly increased bilaterally.

Quite recently Dr. James A. DeWeese has shown deep venous thrombosis by phlebogram (on the fourth day after a dacron shunt graft) as the cause of edema in one patient (Figure 30) and it seems likely that this is the true cause of pedal edema after grafting. Wylie[5] reported a 30 % incidence of popliteal vein thrombosis after

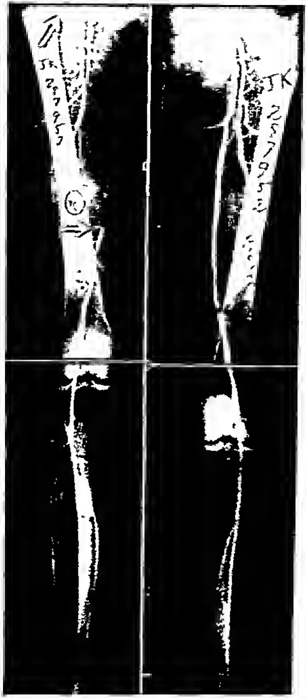

Fig 29 Bilateral femoral arteriography led to by pass grafting for the long superficial femoral arterial block shown on the left and thromboendarterectomy immediately thereafter for the short but symptomatic block shown by the arrow on the right (left leg).

popliteal arterial exploration whether or not direct surgery was performed

Management to date has consisted only of elevation and application of external pressure wrappings because of fear of anticoagulants in the early postoperative period No instance of pulmonary embolism has occurred

Infection

Although an autogenous venous graft appears to be more resistant to infection than does either a homologous arterial graft or a synthetic tube some of the failures occurring in this series were associated with infection in one form or another The methods of prevention of wound infection are too well known to warrant detailed repetition here although it should be pointed out that the technic of tissue management is just as important as is attention to skin preparation in draping Any evidence of infection is an indication for immediate investigation of the wound to determine whether or not this has actually occurred The best chance for continued patency of the graft if infection has occurred appears to be *wide opening of the wound* for drainage since the viable autogenous venous graft is likely to remain patent even in the face of infection if proper drainage and granulations are permitted Conservative management is therefore to be avoided as endangering patency of the graft

Illustrative Case

A 65 year-old white male had a right autogenous venous shunt graft from the common femoral to the popliteal artery because of right calf claudication with absence of distal pulses and arteriographic demonstration of occlusion from the femoral bifurcation to the hiatus in the adductor magnus muscle with good distal reconstitution Postoperatively, pulses immediately returned

A tense hematoma developed in the femoral wound which required removal of sutures on the 4th postoperative day After removal of the hematoma by opening the wound widely infection occurred and was treated by warm saline compresses The proximal portion of the vein graft could be seen and

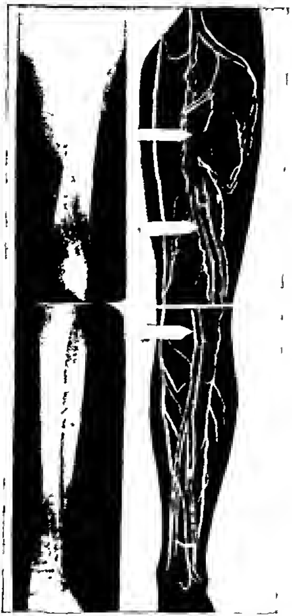

Fig 30 Phlebogram four days after peripheral shunt graft via foot vein illustrating extensive thrombosis of deep veins of calf as well as popliteal and superficial femoral veins. Arrows show thin dye outlines outside large intravenous thrombi (Phlebogram courtesy Dr James A DeWeese.)

palpated as a pulsatile tube lying in the floor of the wound This gradually granulated without difficulty and six weeks postoperatively was healed The distal pulses remained good

Comment The functioning vein graft was clearly evident in the base of this femoral wound and despite contamination and secondary infection occurring after the hematoma was removed, the wound granulated well and there was no interference with the function of the graft

Neuritis

The anatomic proximity of the saphenous nerve to the distal superficial femoral artery where it is dissected for the distal anastomosis in the popliteal region may result in trauma to the nerve by stretching with a subsequent peripheral saphenous neuritis This is manifest by burning pain down the anterior medial aspect of the lower extremity below the knee and is of a type similar to that occurring in the thigh following lumber sympathectomy It may be expected to subside spontaneously although it is troublesome during the weeks while it persists Medication relief has been the only recourse to date for this complication which in a few instances is rather severe

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Chapter X

RELATION TO OTHER OPERATIONS

SINCE SHUNT grafting for peripheral atherosclerotic vascular occlusion is not always the only nor optimal therapy, some discussion of its relation to other available procedures is warranted Non operative measures are omitted from this consideration As in numerous other conditions it is not so much the operative therapy itself which is difficult to evaluate as it is the proper indications for the particular surgical procedure which are difficult to understand Furthermore, accumulating experience and interpretation of that experience varies and dogmatic statements are quite likely to be incorrect and today s optimal therapy may become tomorrow's obsolete management The choice of procedures is further rendered difficult by varied kinds of interpretations of experience, by the usual lack of simultaneous experience with more than one method and by limitation of follow up to short periods With these dangers in mind some observations will be made

Large Vessel Grafts

The surgery of aortic and iliac arterial lesions presents a some what different problem from peripheral replacement because of the difference in size of the lumens of the vessels Large vessels have been satisfactorily replaced by a large variety of synthetic materials, both experimentally and clinically Although accumulating experi ence with aortic homografting indicates that increasing numbers of such grafts degenerate with formation of aneurysms or rupture as time goes on, the same has not to date occurred with the commonly used synthetic materials Furthermore, the large lumen of such replacements allows for the thick neo-intima to be tolerated and continued patency has proven the rule Such straight (or bifur cated) synthetic tubes are therefore the material of choice for re placement of the aorto-iliac arterial system

In a few cases it is necessary to carry the distal extremity of the graft below Poupart s ligament either to the common femoral artery

in the thigh or even down as far as the popliteal artery, usually be cause of atherosclerotic disease in the femoral artery associated with aorto iliac occlusion higher[4] In such an event, the ordinarily used synthetic tubes are made with sufficiently long limbs to reach to the popliteal artery and this should be joined by an end to-side anastomosis to that vessel without any thought of placing a vein graft in this distal position While it appears that vein grafts may in general be the best *material for peripheral use*, it should be clear ly recognized that several of the currently available synthetic tubes have excellent early postoperative patency results and that a syn thetic tube is undoubtedly the material of choice for a graft which starts from one of the great vessels within the abdomen

Thromboendarterectomy

Thromboendarterectomy, which implies the removal of (usual ly organized) thrombus along with the atherosclerotic thickened intima, is a useful procedure under proper conditions and does not deserve the low regard to which it has fallen in some spheres Short occlusions in large vessels such as the aorta or iliac arteries are common indications for direct open thromboendarterectomy The same may be easily performed for a short block in the distal super ficial femoral artery[5 11 13]

Illustrative Case

A 56 year-old white male complained of bilateral calf claudi cation Bilateral arteriograms showed a long superficial femoral block on the right and a short block of the superficial femoral artery at the adductus hiatus on the left (Figure 29)

An *autogenous venous shunt graft* was *placed from common* femoral to popliteal artery without difficulty in the right leg Because this procedure had gone smoothly, the graft was pul sating strongly and the patient s general condition was good, a left popliteal endarterectomy was then performed All pulses were quite apparent on the first postoperative day Twelve months after operation he had returned to full time work, was completely asymptomatic and had excellent pulses at all points

Comment Although bilateral operation in general is be lieved to be unduly risky for fear that both legs may develop

simultaneous complications which will endanger the management of either. In this particular instance the shunt vein graft had proceeded smoothly and was carrying blood extremely well into a quite patent distal arterial circulation and so the simultaneous endarterectomy was performed contralaterally.

The development of newer internal stripping instruments[1,2] which restore the arterial lumen without diminishing caliber have in some hands resulted in fairly good series of peripheral long thromboendarterectomies. Cannon, Barker and Kawakami[*] in 1958 reported 45 thromboendarterectomies where distal patency was present with 66% fair to excellent improvement up to 63 months postoperatively. Their long term results peripherally were admittedly poorer than in large vessel operations and the author believes that such peripheral endarterectomies have a limited usefulness whereas more proximal ones in aorta and iliac arteries are more likely of success.

Illustrative Case

A 51 year-old white male had bilateral calf claudication worse on the left. There were no pulses distal to either femoral artery. Arteriograms (Figure 31a) showed a short occlusion of the superficial femoral artery on the left at the adductor hiatus which was treated by direct thromboenderectomy. He was discharged on the 12th postoperative day with excellent pulses and with a patent artery by arteriography (Figure 31b). He was asymptomatic for four months at which time there was return of claudication in the left leg. This gradually increased and 8 months after the original operation, re-examination showed complete absence of pulses on the previously operated side with only ½ unit of oscillation at the low thigh and only 1/4 in the calf. Percutaneous femoral arteriogram was unsuccessful. An operative popliteal arteriogram showed an excellent distal run-off (Figure 13 on page 57) and an arteriotomy in the common femoral artery showed a good blood flow from the proximal end. A venous shunt graft was placed from common femoral to distal popliteal artery with development of good pulses immediately thereafter.

Comment. This thromboendarterectomy of the distal superficial femoral artery was successful for eight months but then

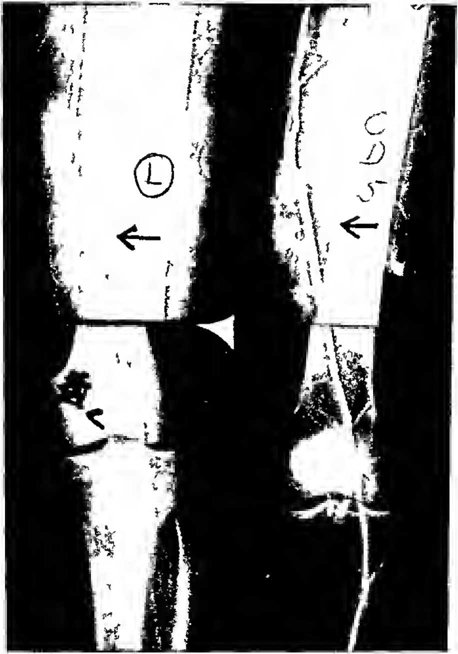

Fig. 51 (*Left*) Short block at adductor magnus hiatus with good reconstitution of popliteal artery. (*Right*) Patent superficial femoral artery on the fifth post operative day following open thromboendarterectomy. Later recurrence of thrombosis necessitated shunt grafting.

> eventually failed because of progression of atherosclerotic disease and suggests that a venous shunt graft should have been done originally The secondary operation was considerably more difficult technically

The combination of proximal thromboendarterectomy with peripheral vein grafting appears to be logical as well as relatively safe procedure because the flow of blood tends to flatten the cut ends of the thickened intima whereas if the same is carried out distally the blood flow tends to tunnel in behind the cut ends and push the intima into the lumen and cause occlusion Proximal endarterectomy is therefore more acceptable with shunt grafting than is distal endarterectomy

If the popliteal artery is narrowed by atherosclerotic deposits to the place where a distal endarterectomy appears mandatory it is often possible to obtain a better point for anastomosis by exploring the more distal popliteal artery or the posterior tibial artery by splitting the calf muscles If a distal thromboendarterectomy is to be performed at all the cut ends of the intima should be carefully sutured with mattress sutures to the outer layer of the vessel in an attempt to prevent tunneling with luminal occlusion Heparinization should be strongly considered following such distal endarterectomy bearing in mind the wound complications which are prone to follow immediate postoperative use of this drug Finally technical failure of thromboendarterectomy should be recognized in the operating room and at times lead to immediate change to a grafting procedure

In certain instances of acute thrombosis or embolism with distal thrombosis it may be impossible to restore blood flow to the distal portion of the extremity because of time lag with adherence of portions of the clot to the wall of the artery or because of inability to clear the distal portions of the vascular tree of thrombus In such an event shunt grafting is to be considered rather than permitting the extremity to remain acutely insufficient of blood with the hope that collateral will develop in time to prevent amputation The distal run off circulation should in such an event be evaluated by operative arteriography prior to placing the by pass graft If thrombus remains in the distal popliteal tree it may be possible to remove

more of this by endo arterial cannulae and suction by a popliteal arterial approach

Lumbar Sympathectomy

The place of sympathectomy in the management of peripheral vascular disease has been debated for a long time without definite conclusions being reached in all regards Theis[12] studied lumbar sympathectomy performed on 100 patients (all of whom had arterial obstructions somewhere between the aorta and the foot) and concluded that 75% of those operated on have definite relief from intermittent claudication " On the other hand, Mavor[9] studied 51 patients with peripheral atherosclerotic occlusion (proved by arteriography) and concluded that the so called beneficial effect of sympathectomy on intermittent claudication has remained haphazard and entirely unpredictable is subjective and not related to the nature of the operation "

There is increasing evidence that the result of lumbar sympathetic ablation is primarily an increase in skin blood flow rather than in muscle blood flow so that while claudication may not particularly be relieved, pre gangrenous skin changes may be reverted[8 11] and subjective improvement be noted Frank skin necrosis, of course, is not effected by sympathectomy

There is no particular reason to debate a choice between shunt grafting and sympathectomy if the former can be done properly because it is obviously more important to deliver a stream of blood under pressure than to relieve peripheral vasospasm There is an increasing tendency toward concomitant sympathectomy to add to the benefit of grafting DeBakey and associates[5] advocate distal sympathectomy at the time of direct surgery for aorto iliac stenosis if the distal arterial tree is involved and Cannon, Barker and Kawakami[2] emphasize its need either prior to or at the time of peripheral thromboendarterectomy. DeTakats[6] recommends lumbar sympathectomy preceding or accompanying all direct arterial surgery Whether such will eventually prove useful is unknown Only an occasional concomitant sympathectomy has been done by the author

However, if grafting is not feasible, sympathectomy may be

done if there appears to be vasospasm which can be released by nerve block or by reflex heating or if it appears that the patient is in danger of losing the extremity with gangrene

Realization that the clinical syndrome of Buerger s disease is often simply a presenile or early form of atherosclerosis has indicated that sympathectomy may be valuable for such early forms of atherosclerosis

Amputations

It has been clearly shown that many amputated extremities became gangrenous because of failure of the distal superficial femoral or popliteal artery with patent distal vessels so that a graft could have been placed This indicates that serious consideration should be given to arteriographic evaluation of the distal circulation prior to amputation Surprisingly patent distal circulation may be found by arteriography of amputated extremities [8] in the face of apparently severe peripheral vascular insufficiency particularly if the femoral or popliteal artery has become suddenly occluded by thrombosis (or embolism) Roberts and Hoffman [10] were able to do peripheral grafts in 30% of 49 patients presenting with conditions prompting amputation of the leg Martin [8] has advocated grafting to any patent popliteal artery in a leg threatened by gangrene ignoring the arteriographic pattern

Salvage of extremities by proper evaluation of the distal run off and of the possibility of grafting prior to (or to prevent) amputation is clearly needed An arteriogram or popliteal arterial exploration is advocated prior to any amputation to learn whether it can be avoided

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Chapter XI

FURTHER DEVELOPMENT OF DIRECT ARTERIAL SURGERY

THE STREAM of progress in peripheral direct arterial surgery which in the past decade has been a landslide of new developments appears about to enter a quieter period of evaluation As short term reports of immediate operative results give way to long term follow up studies of progression of disease as well as results of operative procedures the proper indications for various forms of direct arterial surgery will become manifest Restraint of over enthusiasm for certain procedures will undoubtedly occur The salvage of function and of tissue must be accomplished with reasonable risk cost pain and prognosis

Since the underlying disease process continues despite the palliation of various direct arterial procedures it is to be hoped that non surgical therapy for prophylaxis and/or treatment of atherosclerosis will develop and make surgical management needless. The importance of efforts in this direction can hardly be over-emphasized in view of the present incidence of arteriosclerosis as a cause of death and disability The development of methods to allow transplants of complex tissues between individuals or even between species is an intriguing field When currently insoluble problems are understood such replacement of worn parts of the human machine will open new fields for progress

At the same time that dramatic new fields are studied unanswered questions in old ones must be remembered Despite widespread use of lumbar sympathectomy its role has never been completely evaluated and there continues to be debate between various authorities as to its value Development of new methods of study such as the flow meter and the polarograph give some promise of elucidating mechanisms involved in sympathectomy as well as in direct arterial surgery

Various mechanical suturing devices have been reported from time to time It is at the moment doubtful that even the most com

plicated of these (such as the one reported from Russia) can approach the delicacy of technic of an individual surgeon exercising judgment and experience in regard to the particular technical problem under consideration

Whether autogenous venous grafts will prove the material of choice for long peripheral shunts will in the final analysis be determined by long term studies of them as well as of other materials and of the underlying disease process The importance of such follow up studies place a considerable responsibility on each individual surgeon performing direct arterial surgery to supervise carefully the long term as well as short term postoperative course and thus to aid in the final determination of the place of direct arterial surgery in the management of peripheral atherosclerosis

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